CIRCUIT MATH:

Voltage, Resistance, and Current

Scenario:

You are a **scientist** who has been charged with discovering the mathematical principles behind the relationships among **voltage**, **resistance**, and **current** in simple circuits.

You are in a race with other scientists to see who can make this discovery first and claim all the credit – and maybe get the solution named after you!

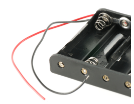
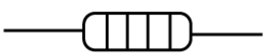
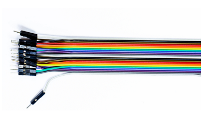
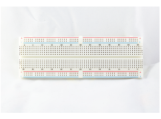
You will build **circuits** with different levels of resistance and see what happens to the current. You will use the same voltage level for each circuit – 2 AA batteries.

To Get Started:

- **Get in a team of three**
- **Number off your team members as 1, 2 and 3**
- **Find the role instructions for each team member's assigned role**

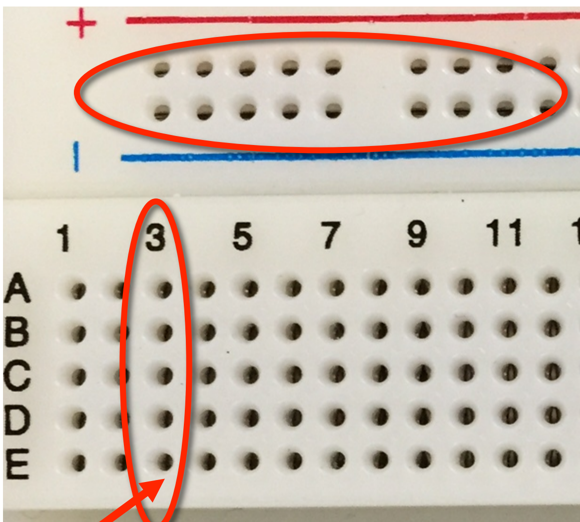
Parts – What You Need

Parts Sheet:

Part	Picture	Circuit Symbol
2 AA Batteries – the power source		
Battery holder – an easy way to connect your batteries to a circuit		
LED – A small light (LED stands for "light-emitting diode")		
Resistor – Something that reduces the amount of current by "resisting" the flow of electricity. Used to prevent parts like LEDs from being burnt out by high current. We will use resistors with different levels of resistance (Ω). Ω stands for "ohm. Locate the following resistors: 100Ω, 1kΩ, 10kΩ, 100kΩ."		
Wire – Something that carries a electricity – a "current" – through a circuit.		
Alligator Clips – Wiring to easily connect two pieces of a circuit together		
Jumper Wires – Pre-cut wires that connect ports on a breadboard		
Breadboard – A tool engineers use to connect circuits to try them out. (In the old days, they connected circuit pieces on real boards for slicing bread.)		
Multi meter – Device used to measure voltage or current in a circuit		

Anatomy of a Breadboard

A **breadboard** is a tool engineers use to connect circuits to **try them out**. In the old days, they connected circuit pieces on real boards for bread.



Rows on the Breadboard

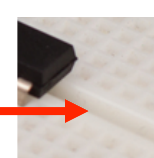
- Each of these numbered **rows** on one side of the breadboard are **connected** to each other.
- For example, all the holes in row 3 on the one side of the board are connected.
- If you put a wire into one hole in row 3, and another wire into a different hole in row three, you have connected those wires.

Power Rails

- These "+" and "-" lines along the sides of the bread board are called **power rails**.
- Any power sources are typically connected here.
- You will connect the positive (red) lead wire from the power source (the battery pack) to any hole on the positive (red) power rail.
- You will connect the negative (black) lead to any hole on the negative (blue) power rail.
- All holes along a positive or negative rail on one side of the breadboard are connected to **each other** – but NOT to the bread board
- You need to run a wire from the positive power rail power your circuit.
- And you need another wire from the end of your circuit back to the negative rail. That's how you run power through your circuit.

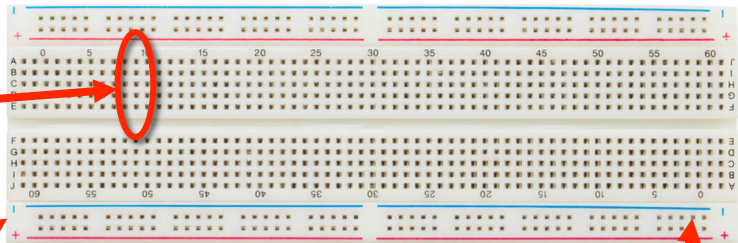
DIP Ravine

- However, the big gap down the middle of the breadboard electrically **separates** the two halves of the board.
- Row 3 on one side of the gap is **NOT** connected to row 3 on the other.
- This is so that people can put computer chips in the middle and not have the pins on opposite sides connect.



Quiz – ARE YOU READY?

Take this quiz to make sure you are ready to build your first circuit!



1.	The "+" and "-" columns along the sides of the breadboard are called power rails.	TRUE	FALSE
2.	The positive/red lead wire from a battery pack should be connected to the positive ("+") power rail on the breadboard.	TRUE	FALSE
3.	The negative/black lead wire from a battery pack should be connected to the negative ("-") power rail on the breadboard.	TRUE	FALSE
4.	Each hole in a row on the same side of the DIP ravine (the gap in the middle) is connected.	TRUE	FALSE
5.	In order to connect the power source to the circuit, you need to run a wire from the positive power rail to the first element of your circuit, and another wire from the last element of your circuit back to the negative power rail.	TRUE	FALSE

Answers: Each of these are TRUE.

Roles

Role #	Role Name	Role
1	**Organizer and Project Director**	• Find the right parts for each circuit • Keep the team organized through building each circuit and recording data • Verify that the wiring person has wired the circuits correctly • Replace parts in bag after use
2	**Circuit Wiring**	• Connect the circuit using the diagrams and the parts given • Make sure you double check that all your connections in in the right place
3	**Measurement and Data**	• Measure the current for each circuit using the multi meter and record the data on the data sheet • Help the organizer and wiring person ensure they are using the right resistor for each circuit experiment

Role Instructions:

Role 1. Organization and Project Director

- Review the Parts Sheet and identify each part
- Do not lose track of which resistor is which! It might be helpful to tape a label on to each one indicating the resistance
- Hand the breadboard, batteries, and battery holder to team member #2
- Hand the multi meter and alligator clips to team member #3
- Using the circuit diagrams, sort the resistors into the sizes needed for each
- Locate the parts for **Circuit #1** and lay them out
- When the wiring person has powered the breadboard, hand them a 100-ohm **(100Ω)** resistor
- Keep track of which resistor is which!
- As each experiment is completed, put any parts you are done with back into the project bag

Circuit Sequence & Organization:

Role 1. Organization and Project Director

- Use the below parts list to provide the right parts for each circuit
- Make sure you keep track of which resistor is which, and that your data person knows which circuit and resistance you are testing!
- Circuit #6 and #7: Only if time permits

Parts For Each Circuit

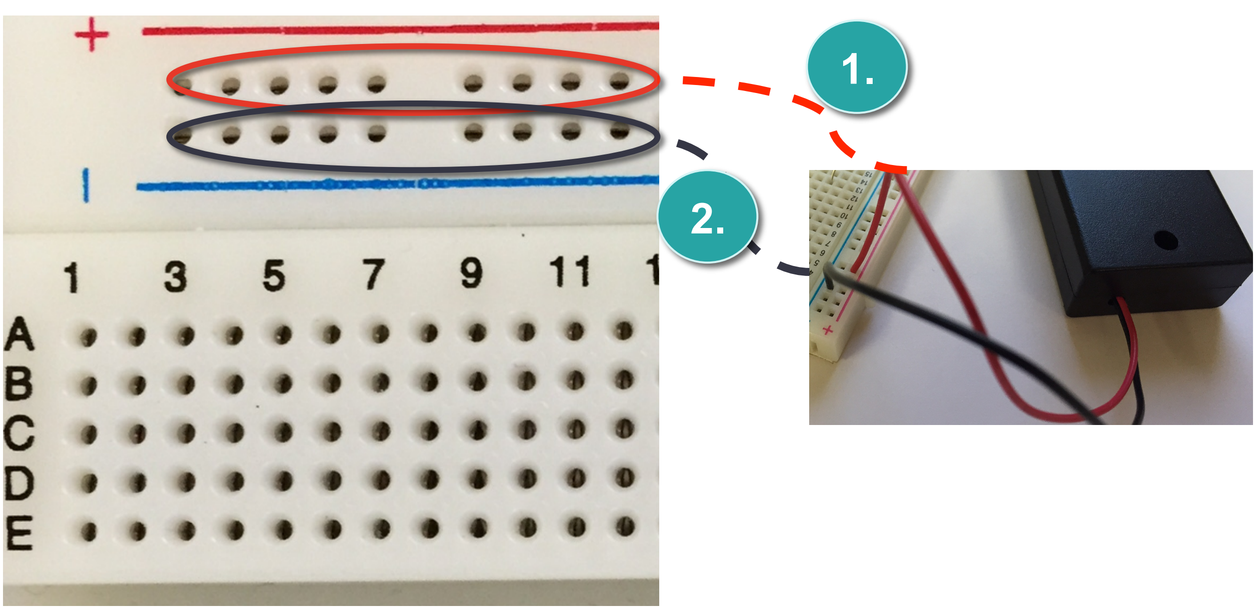
Circuit #1:	• LED, 100Ω resistor, 2 jumper wires, plus the powered breadboard wired by team member #2
Circuit #2:	• Take out LED. Add multi meter, 2 alligator clips, and the 2 short red copper wires
Circuit #3:	• Replace 100Ω resistor with 1000Ω (1kΩ) resistor
Circuit #4:	• Replace 1000Ω resistor with 10,000 ohm (10kΩ) resistor
Circuit #5:	• Replace 10kΩ resistor with 100,000 ohm (100kΩ) resistor
Circuit #6:	• Replace 100kΩ resistor with 100Ω resistor, but use rows 2 and 5 rather than 2 and 9. Add another 100Ω resistor between rows 5 and 9.
Circuit #7:	• Replace both 100Ω resistors with 1000 ohm (1kΩ) resistors

Role: 2 Step: 1

Role Instructions:

Role 2. Breadboard and Wiring

- Get your breadboard, battery holder, and batteries from your team organizer
- Identify the "power rails" on the breadboard (the red and blue lines on the sides with + and -)
- Load the batteries into the battery holder
- 1. Connect the red battery holder wire into the positive power rail
- 2. Connect the black battery holder wire into the negative rail
- Your breadboard now has power!
- Now you will connect the power rails to the main part of the breadboard – see next page



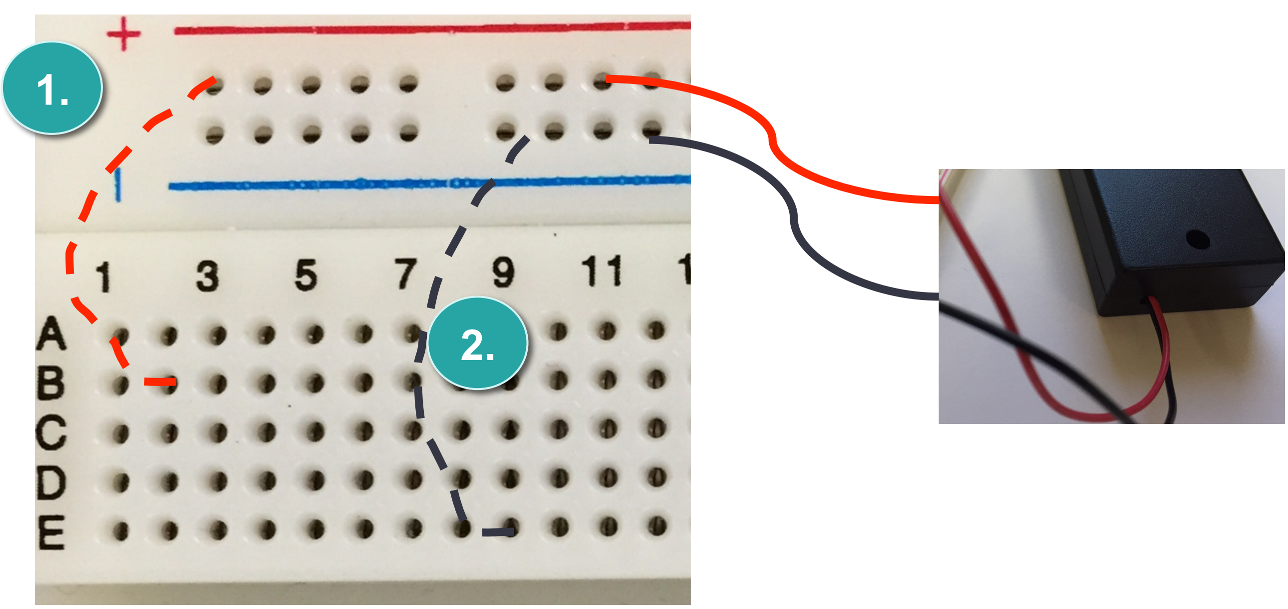
Role: 2 Step: 2

Powering the Breadboard:

Role 2. Breadboard and Wiring

1. • Now you can run a jumper wire from the positive rail into a row on the main part of the breadboard (row 2)
2. • And run another jumper wire from the negative rail to a different row (row 9)

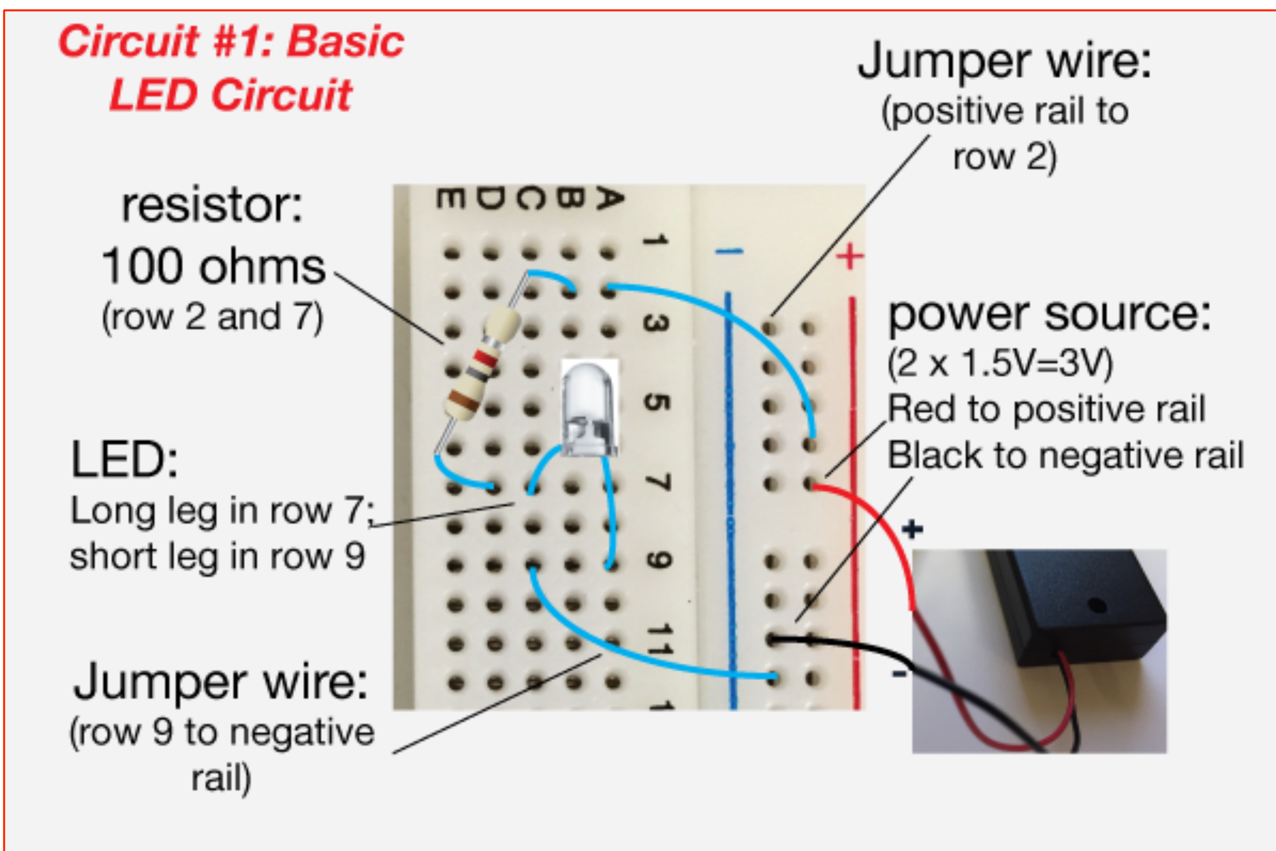
These are jumper wires. Plain copper wire like these (right) work, too.



Build Circuit #1:

Role 2. Breadboard and Wiring: Build Circuit #1

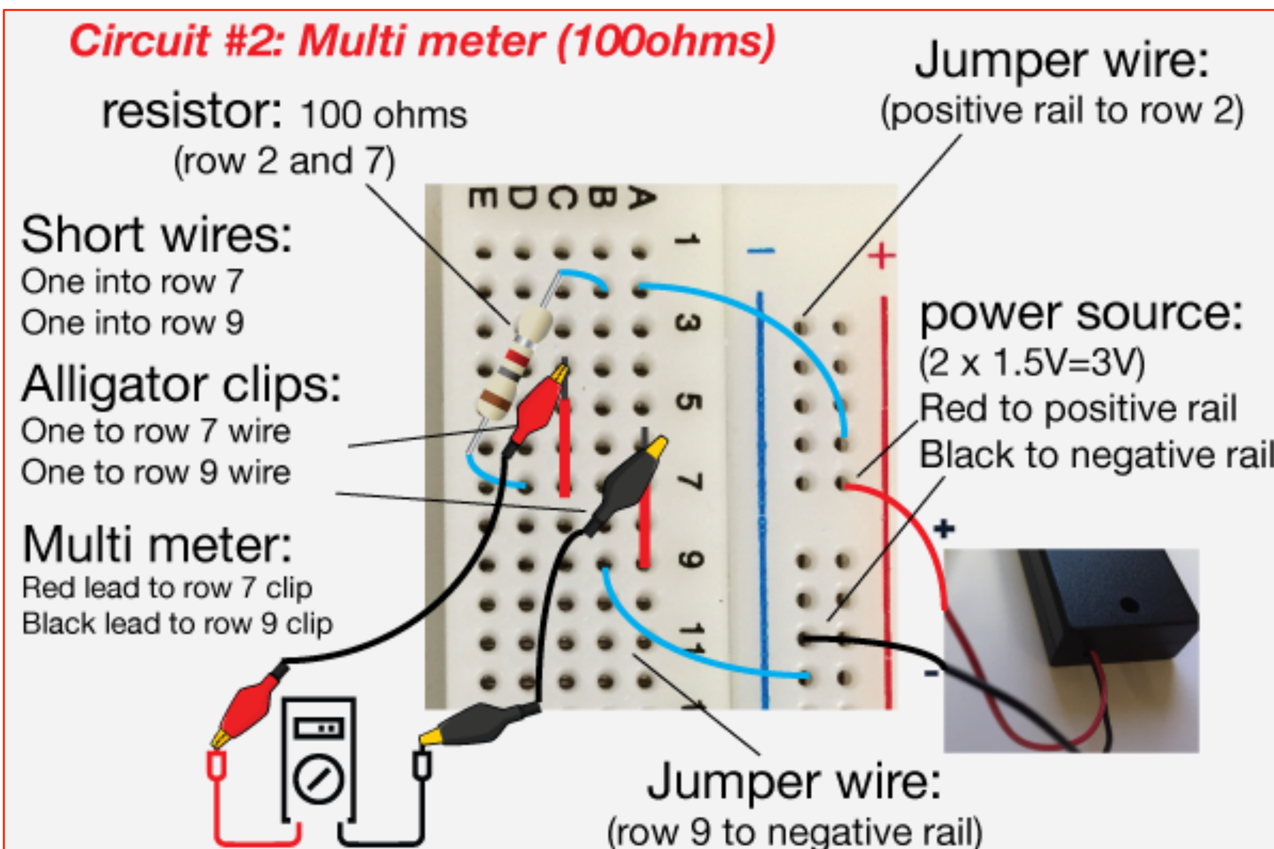
- Get your first resistor and the LED from your organizer
- Look at your LED and identify which leg is **longer**
- Place them as shown – resistor between rows 2 and 7
- Long leg of the LED in row 7; short leg in row 9
- Your LED should light up, verifying that you have connected everything properly
- Temporarily pull out your red battery lead until you are done building the next circuit (don't forget to reconnect!)



Role: 2 Step: 4

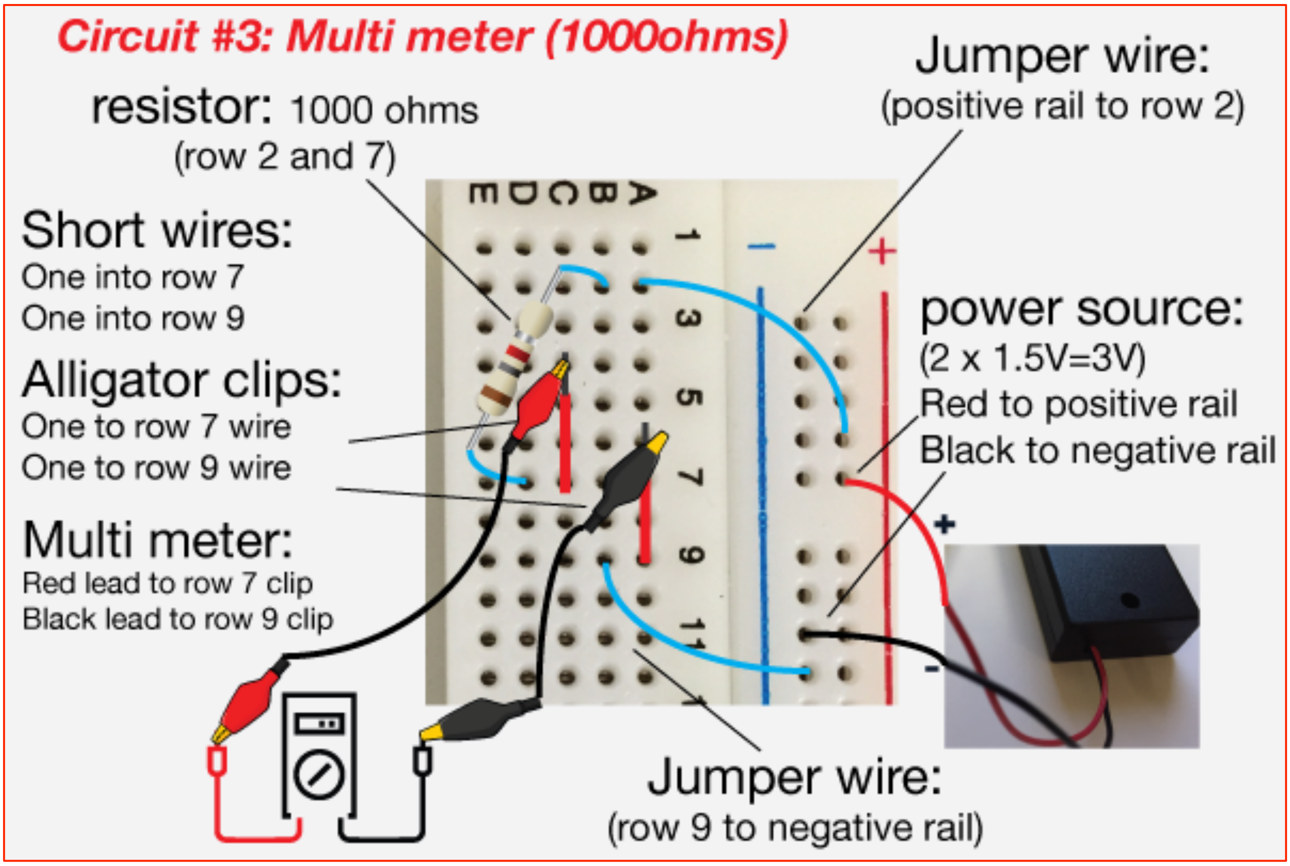
Role 2. Breadboard and Wiring: Build Circuit #2

- Hand the LED back to your organizer; get multi meter, alligator clips, and two short red wires in exchange
- Place one short wire in row 7 with the end sticking up out of the way; place the other short wire in row 9
- Connect the red prong of the meter to row 7 by connecting its alligator clip to the red wire in 7
- Connect the black prong of the meter to row 9 by connecting its alligator clip to the red wire in row 9
- Make sure your red battery lead is connected
- Let your data person know the circuit is ready for data collection. Your data person will measure the current.



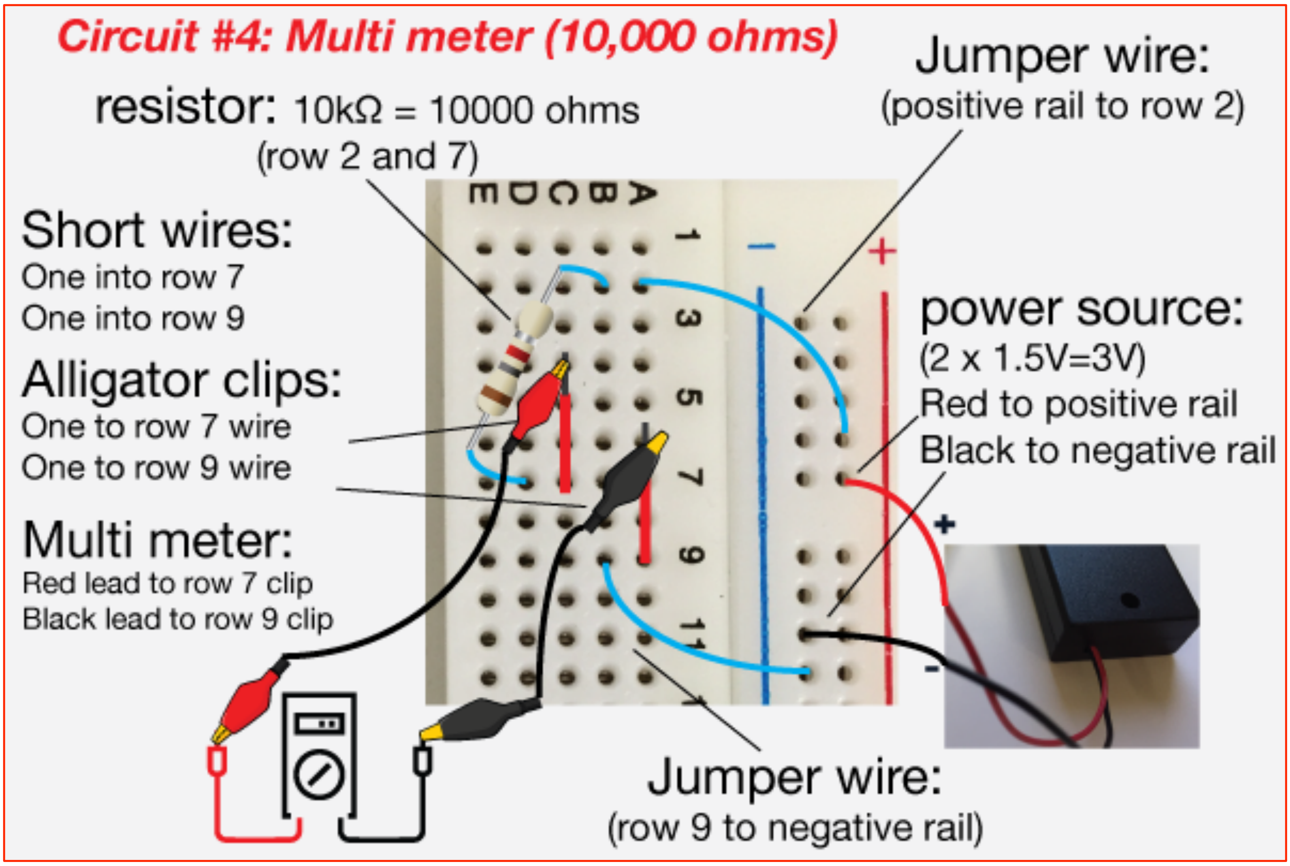
Role 2. Breadboard and Wiring: Build Circuit #3

- Exchange your resistor for the next size resistor – your organizer should hand you the right one
- Be sure you put the new resistor in the same rows – 2 and 7
- Make sure your red battery lead is connected
- Let your data person know the circuit is ready for data collection. Your data person will measure the current.



Role 2. Breadboard and Wiring: Build Circuit #4

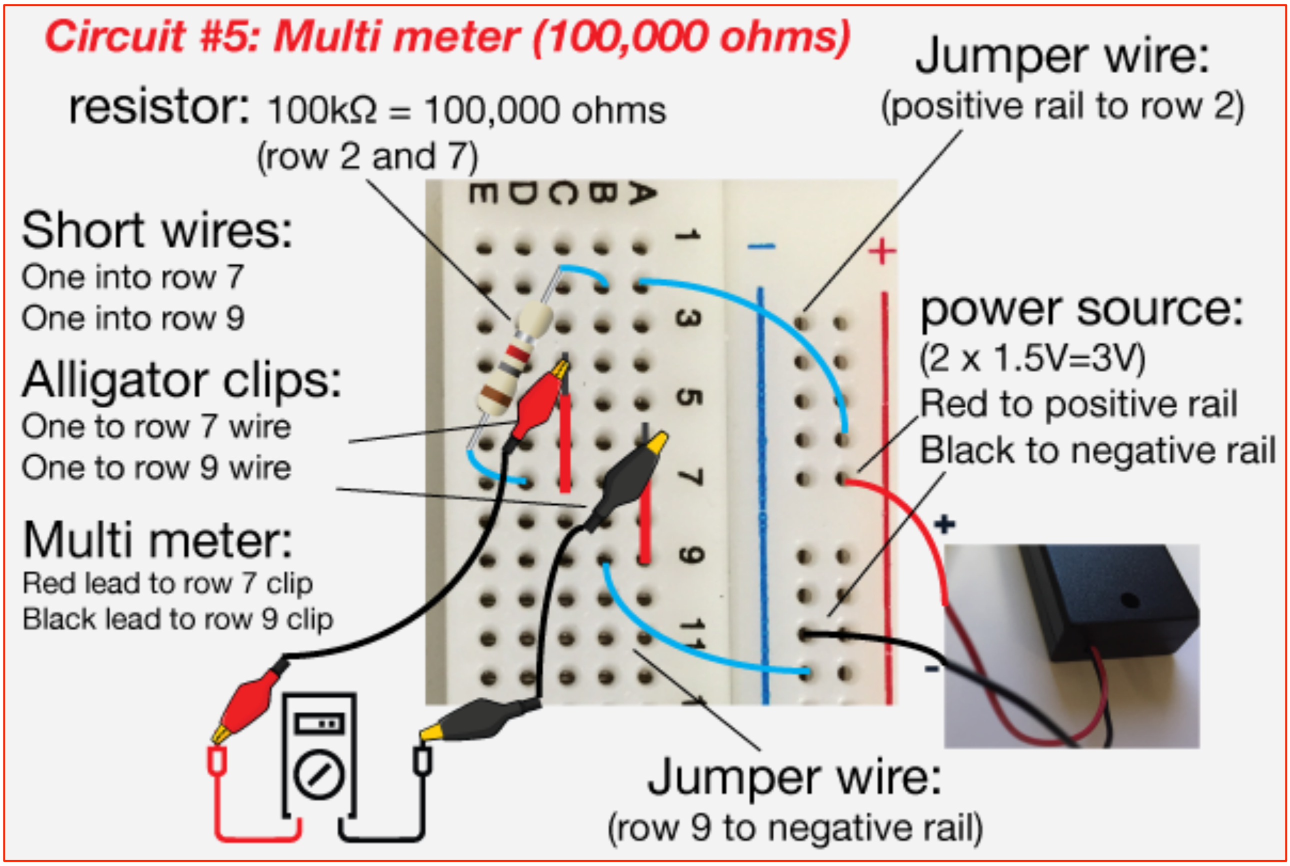
- Exchange your resistor for the next size resistor – your organizer should hand you the right one
- Be sure you put the new resistor in the same rows – 2 and 7
- Make sure your red battery lead is connected
- Let your data person know the circuit is ready for data collection. Your data person will measure the current.



2025 kids

Role 2. Breadboard and Wiring: Build Circuit #5

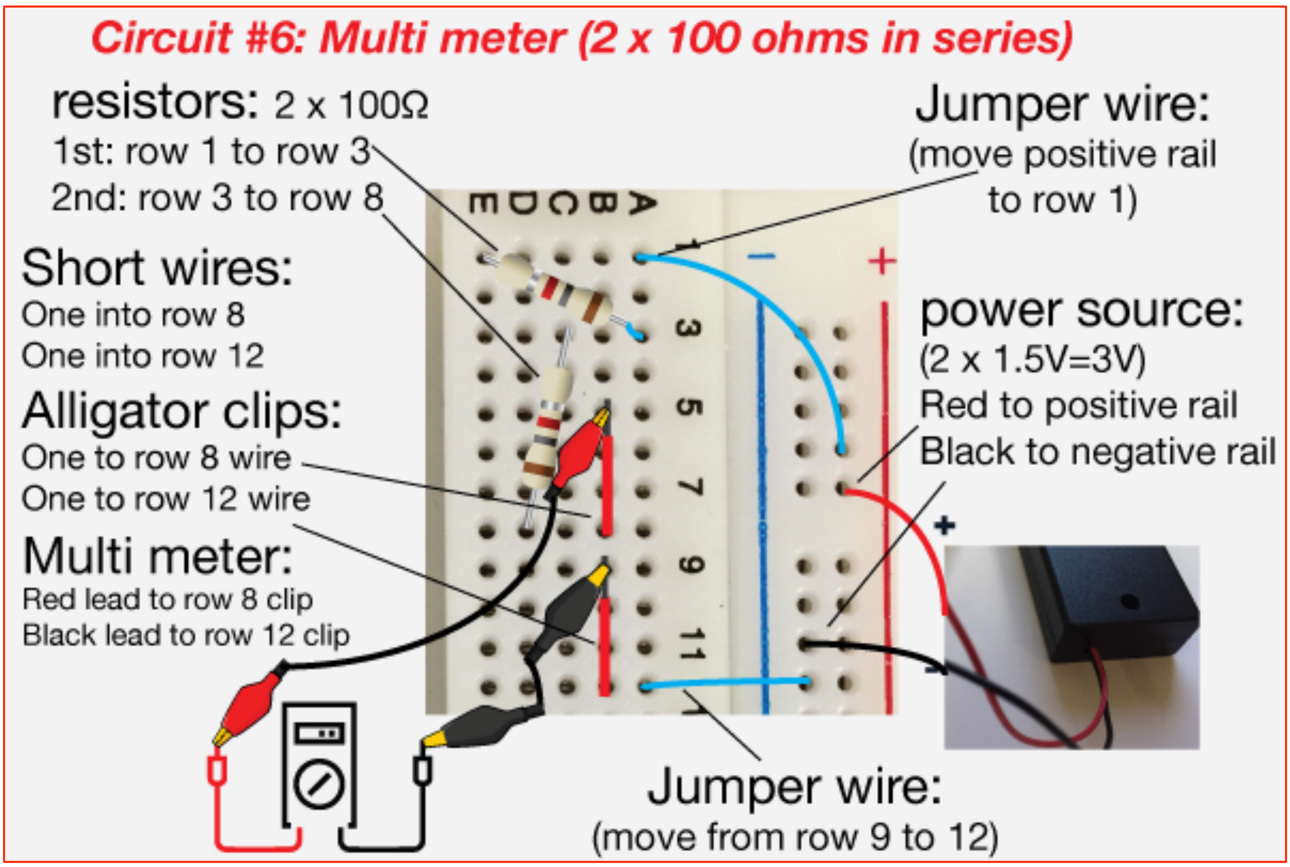
- Exchange your resistor for the next size resistor – your organizer should hand you the right one
- Be sure you put the new resistor in the same rows – 2 and 7
- Make sure your red battery lead is connected
- Let your data person know the circuit is ready for data collection. Your data person will measure the current.



Role: 2 Step: 8

Role 2. Breadboard and Wiring: Build Circuit #6

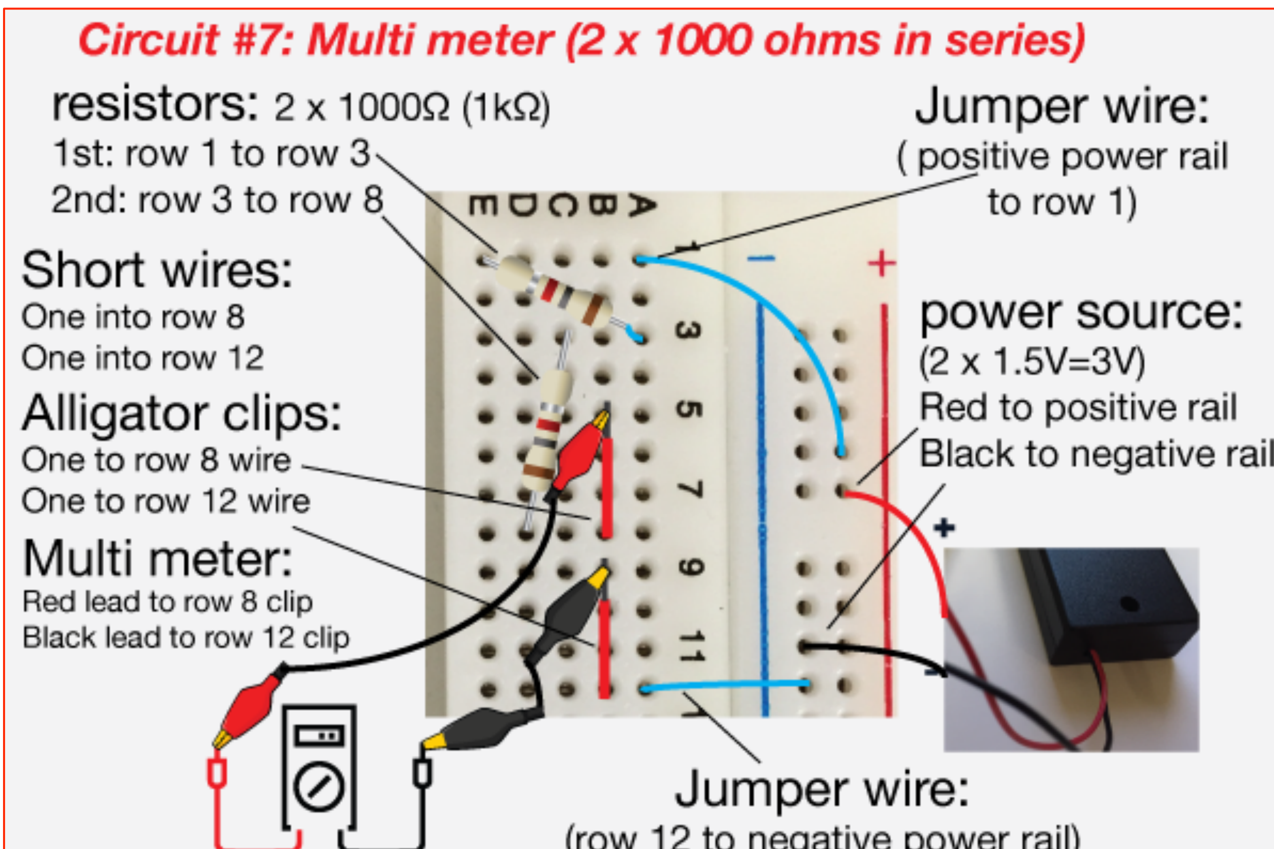
- You will use two 100Ω resistors placed “in series” – so that the current flows through the first one and then through the second one
- You need to move a few things on your circuit to make space for two resistors:
  - Move the negative rail jumper wire from row 9 to 12
  - Move the positive rail jumper wire from row 2 to row 1
  - Move your row 9 test lead and alligator clip to row 12
  - Move your row 7 test lead and clip to row 8
  - Your first resistor will be from row 1 to row 3
  - Your second resistor will be from row 3 to row 8
- Let your data person know the circuit is ready for data collection. Your data person will measure the current.



Role: 2 Step: 9

Role 2. Breadboard and Wiring: Build Circuit #7

- This time you will again use two resistors in series – but this time the resistors will both be 1000Ω (1kΩ) resistors
- Again the current will flow through the first one and then through the second one
- You will use the same circuit setup as Circuit #6, simply replacing the two 100Ω resistors with the two 1000Ω resistors in exactly the same place:
  - Your first resistor from row 1 to row 3
  - Your second resistor from row 3 to row 8
- Let your data person know the circuit is ready for data collection. Your data person will measure the current.



Role: 3 Step: 1

Role Instructions:

Role 3. Measurements and Data

- Gather the data sheet and circuit diagrams
- Review the conversions sheet and data sheet closely
- Get the multi meter and alligator clips from your team organizer – you will use the clips to connect the multi meter to the circuit
- Clip one alligator clip to the red lead of the meter
- Clip the other alligator clip to the meter’s black lead
- Locate the 200mA and 20mA sections of the multi meter. Use the 200mA until you get to the 100kΩ resistor circuit; then use 20mA.

*When you get to the **100kΩ** resistor, you will need to use the **20mA** setting on the multi-meter; for all other resistors, you will use **200mA***

The DCA section of the multi meter is for measuring direct (not alternating) current. Current is measured in Amperes, so DCA stands for Direct Current Amperes.

Role: 3 Step: 2

Units and Conversions to Know:

- **Voltage** is measured in Volts (**V**)
  - Each AA battery is 1.5V
  - So, the Voltage in this circuit is 2 x 1.5V= **3V**

- **Resistance** is measured in Ohms (**Ω**)
  - This project uses resistors from 100Ω to 100,00Ω
  - For larger values of resistance, kilo-ohms are often used
  - 1 kilo-ohm (1 kΩ) is 1000 ohms
  - 10 kΩ = 10,000 ohms
  - 100 kΩ = 100,000 ohms
  - 1 Ω = 1/1000th of a kΩ
  - If you use kΩ for your calculations, you will end up with mA for your current results (recommended)

- **Current** is measured in Amperes (**A**)
  - For small currents, milli-amperes (mA) may be used
  - 1 A = 1000 mA
  - 1 mA = 1/1000th of an Ampere

Role: 3 Step: 3

Measurement Instructions:

Role 3. Measurements and Data

- You do not need to measure anything for the LED circuit (Circuit #1)
- In the following steps, your multi meter readings should not be zero if your circuit is wired correctly. If you get a zero reading, double check your connections and ask for help if needed
- For **Circuit #2**, turn multi meter to the 200mA setting and record the value shown on the meter on to your Data Sheet. Turn off the meter until Circuit #3 is ready.
- Perform the same step for **Circuit #3**, recording in the Circuit #3 row in the Data Sheet
- Repeat for **Circuits #4** and **#5**. (You will need to use the 20mA setting for Circuit #5.) Do you see a pattern? By how much does the current change when the resistance changes?
- If your team has time, build **Circuit #6** (ask for the extra 100 ohm resistor) and read your current value. How does it compare to Circuit #2?
- If your team has time, build **Circuit #7** (ask for the extra 1000 Ω resistor) and read your current value. How does it compare to Circuit #3?

Role: 3 Step: 4

Data Sheet:

To Do: See if you can figure out the mathematical relationship between voltage, current, and resistance in a simple circuit using the data below.

Hint: *Because the meters can be a little off in their measurements,* ***round*** *the numbers you get.*

Hint #2: *Units Matter! Use the same resistance unit for all your calculations* – don't mix and match ohms and kΩ! *Using kΩ* will make your math easier.

Circuit	Voltage (V)	Resistance (ohms – Ω)	Current (mA)
#2	3V	100 Ω (0.1kΩ)	________
#3	3V	1000Ω (1 kΩ)	________
#4	3V	10,000Ω (10 kΩ)	________
#5	3V	100,000Ω (100 kΩ)	________
#6	3V	200 Ω (0.2kΩ) - optional	________
#7	3V	2000Ω (2 kΩ) - optional	________

TEACHER / LEADER NOTES

This project is set up as a group project, done in teams of **three**. (For teams of two, combine Roles 1 and 3.) Before starting work, make sure each role has the instructions specific to their role.

Project Approach

Engineering projects can be intimidating. A key habit of mind to develop is the acceptance that you do not know the answer up front and must be willing to work to find it.

The way we approach projects is to:

1. Start with something fairly simple to help the kids build some familiarity, experience, and **confidence** in the area.
2. **Extend** the project into something to deepen the knowledge, and to stretch the kids **outside** of their **comfort zone**.

In this project, the "simple" effort is to connect the circuit simply to make the LED light up before adding the multi meter to the activity.

Suggested Timing

The activities in this project may be spread out over multiple days. For example,

Day 1: Build Circuit #1 to to learn how to use a breadboard. We recommend starting with having the kids read the **Anatomy of a Breadboard** and the **Parts Sheet** closely.

Day 2: Build Circuits #2-5 and enter the measure current values onto the the data sheet, with time for discussion of the results.

Day 3: Circuits #6 and #7: Discuss what the students think the results will be, then build Circuits #6 and #7 to see what happens to the measured current when two resistors are placed in series in a circuit. Compare the results to predictions.

Project Kit Preparation

It's highly recommended that you **label** each resistor for easy identification by the kids and leaders. Those of us with older eyes have a bit of trouble identifying them from the color stripes on each.

We just created small paper labels (100Ω, 1000Ω, etc.) and taped them onto the body of each resistor.

All of the components in this project are off-the-shelf components and are identified in the Parts Sheet. Contact us if you get stuck.

Troubleshooting

- The most common reason for an LED to not light up is that it was placed backwards in the circuit. Current only flows one way through an LED. Make sure the long leg of the LED is toward the positive power input.
- Often two circuit elements that should be connected are not. For example, the positive power is connected into row 2, but the resistor starts in row 3. Circuit elements are connected by putting the OUT of one element in the same row as the IN of the next.
- Students sometimes forget to connect the power rails to the circuit. The positive power rail needs to connect to the (IN leg of) the first circuit element; the negative power rail needs to connect to the (OUT leg of) the last circuit element.
- Occasionally one of the wires is not completely placed into a hole on the breadboard and the loose wire does not close the circuit.
- Sometimes the students forget that the rows on different sides of the DIP ravine are not connected. For example, the power will be connected to row 2 on one side of the ravine, but the resistor will be connected to row 2 on the other side. This is an open circuit – no current will flow.

Answer Key

The values measured by the multi meter are not always the precise numbers predicted by the math, due to device calibration and accuracy variations.

However, the relationship the students should be able to discern, when the circuits are wired correctly (with the right resistance values for each):

Voltage (in volts) = **Current** (in mA) times **Resistance** (in kΩ)

Or, since V represents volts, R represents resistance, and I represents current:

$V = I * R$ and **$I = V / R$**

For the resistors placed in series (one after the other) in a circuit, the total resistance is the sum of the resistance of each.

For example, two 100Ω resistors placed in series are like a single 200Ω resistor. The two 1000Ω resistors placed in series are like a single 2000Ω resistor. The relationship between current, voltage, and resistance is exactly the same as above, except using the R value for the total (summed) resistance.

On the other hand, if the resistors were placed “in parallel” – e.g., both resistors between row 2 and row 7, then the total circuit resistance is NOT a simple sum of the two resistances. We did not cover resistors in parallel in this project – but may in a future project!