PHYSICAL COMPUTING 1: CIRCUITS

CSE 590 Ubiquitous Computing | Lecture 5 | April 22

Jon Froehlich • Liang He (TA)

DESIGN USE BUILD

MAKEABILITY LAB

PAUL G. ALLEN SCHOOL OF COMPUTER SCIENCE & ENGINEERING

UNIVERSITY of WASHINGTON

SCHEDULE TODAY: 6:30-9:20

06:30-06:40: Physical Computing Module & Overview of A3 Interactive Night Light

06:40-07:00: Discussion of required reading led by Jordan Raisher

07:00-07:05: Optional discussion led by Gang Chen (link)

07:05-08:00: Intro to basic circuits with exercises

08:00-08:05: Break

08:05-08:20: A2 Debrief. Who wants to share about their project?

08:20-09:20: Intro to Arduino with exercises

LEARNING REFLECTION & WHAT'S AHEAD

1 Applied signal processing & ML in ubiquitous computing → **2** Physical computing (electronics, embedded systems, *etc.*) → **3** Wearable comput

Methods:

Basic signal processing approaches such as signal transforms, frequency analysis, and visualization

Basic ML approaches such as rule-based, shape-based, and mode-based inference systems

Interactive inference system design

Toolkits & Languages:

Android, Jupyter Notebook, scipy, numpy, & sci-kit learn

Java, Python

General:

Reading academic literature to inform approaches

Methods:

Basic circuit understanding such as voltage, current, resistance, Ohm's Law, *etc.*

Basic understanding of sensors and actuators and how to use them

Basic understanding of computer vision approaches and how to use them

Physical computing system design

Toolkits & Languages:

Android, Arduino, OpenCV

Java, C

The remaining assignments will have some embedded systems component with Arduino

One of the most sweeping — and unintended — transformations that the **desktop computing paradigm** has brought about is the extent to which the **physical performance of work has homogenized**.

Scott Klemmer, Bjoern Hartmann, Leila Takayama

From: *How Bodies Matter: Five Themes for Interaction Design*

DIS, 2006


How Bodies Matter: Five Themes for Interaction Design

Scott R. Klemmer, Björn Hartmann
Stanford University HCI Group
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One of the most sweeping — and unintended — transformations that the **desktop computing paradigm** has brought about is the extent to which the **physical performance of work has homogenized**. For certain activities, such as writing this paper, the keyboard interaction paradigm appropriately leverages our bimanual dexterity. But, with a keyboard and mouse interface, **the use of our bodies** for writing a paper is the same as for editing photographs. And playing music. And communicating with friends and family. And anything else that one might want computation for.

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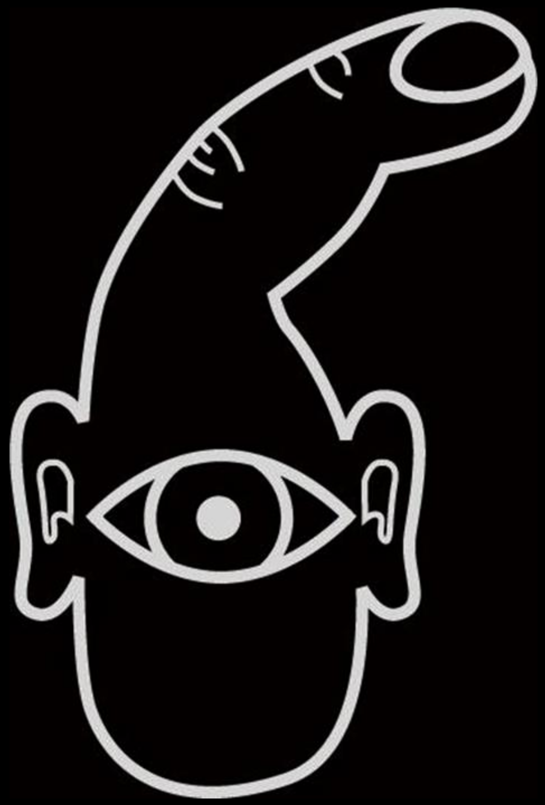
ABSTRACT

How the **computer has traditionally seen us…**



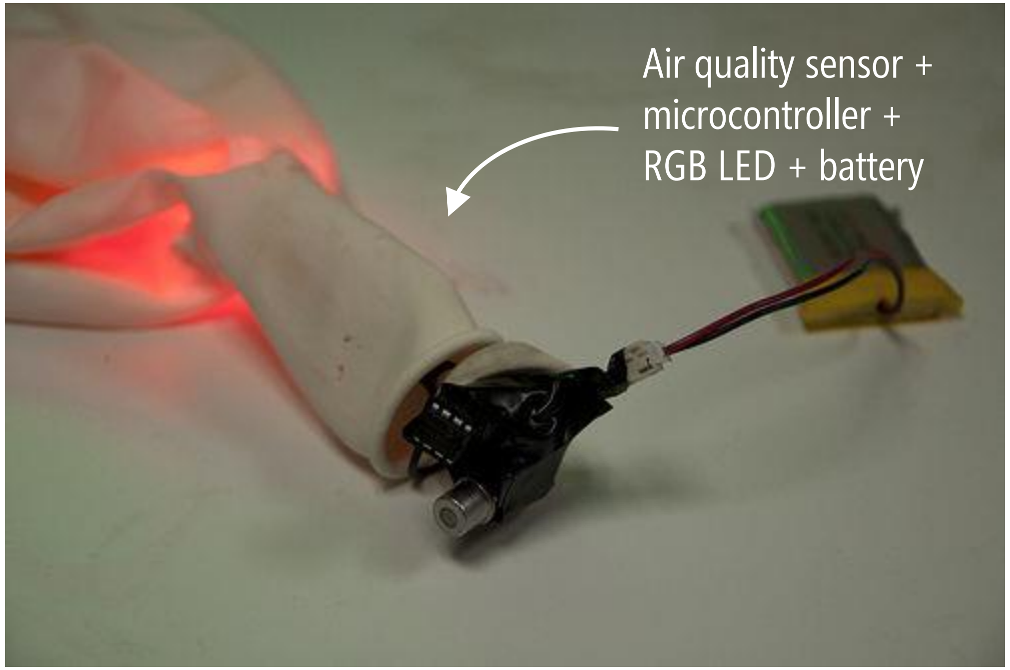
O'Sullivan and Igoe, *Physical Computing*, 2004, p. xix

With Physical Computing, we are going to explore custom input and output to computers (beyond just desktops and smartphones) and embedding computation in artifacts.

PHYSICAL COMPUTING PROTOTYPE EXAMPLES

AMBIENT AIR POLLUTION SENSORS

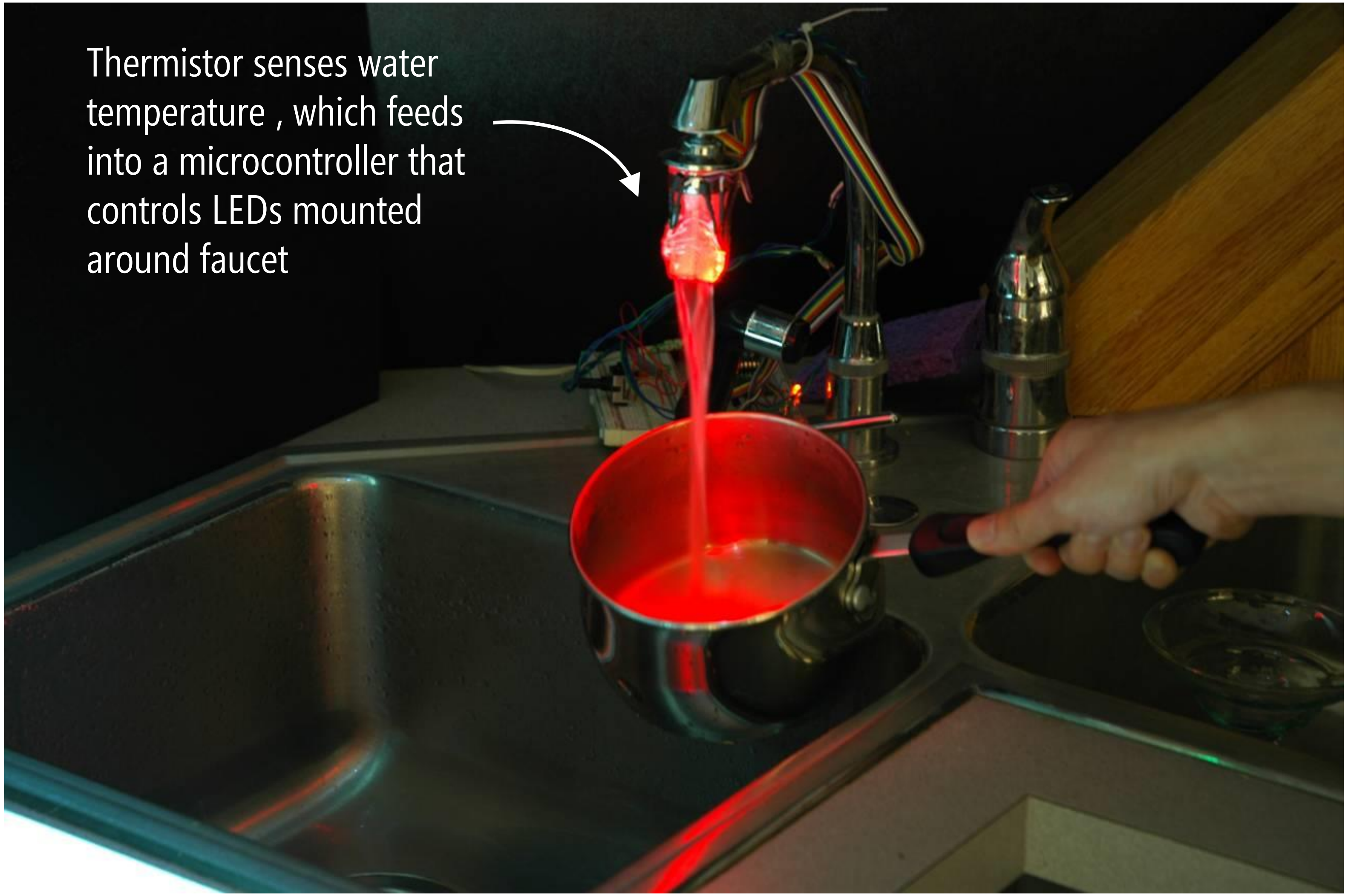
Kuznetsov *et al.*, Red Balloon, Green Balloon, Sensors in the Sky, *UbiComp2011*


Air quality sensor +
microcontroller +
RGB LED + battery


Diesel

PHYSICAL COMPUTING PROTOTYPE EXAMPLES

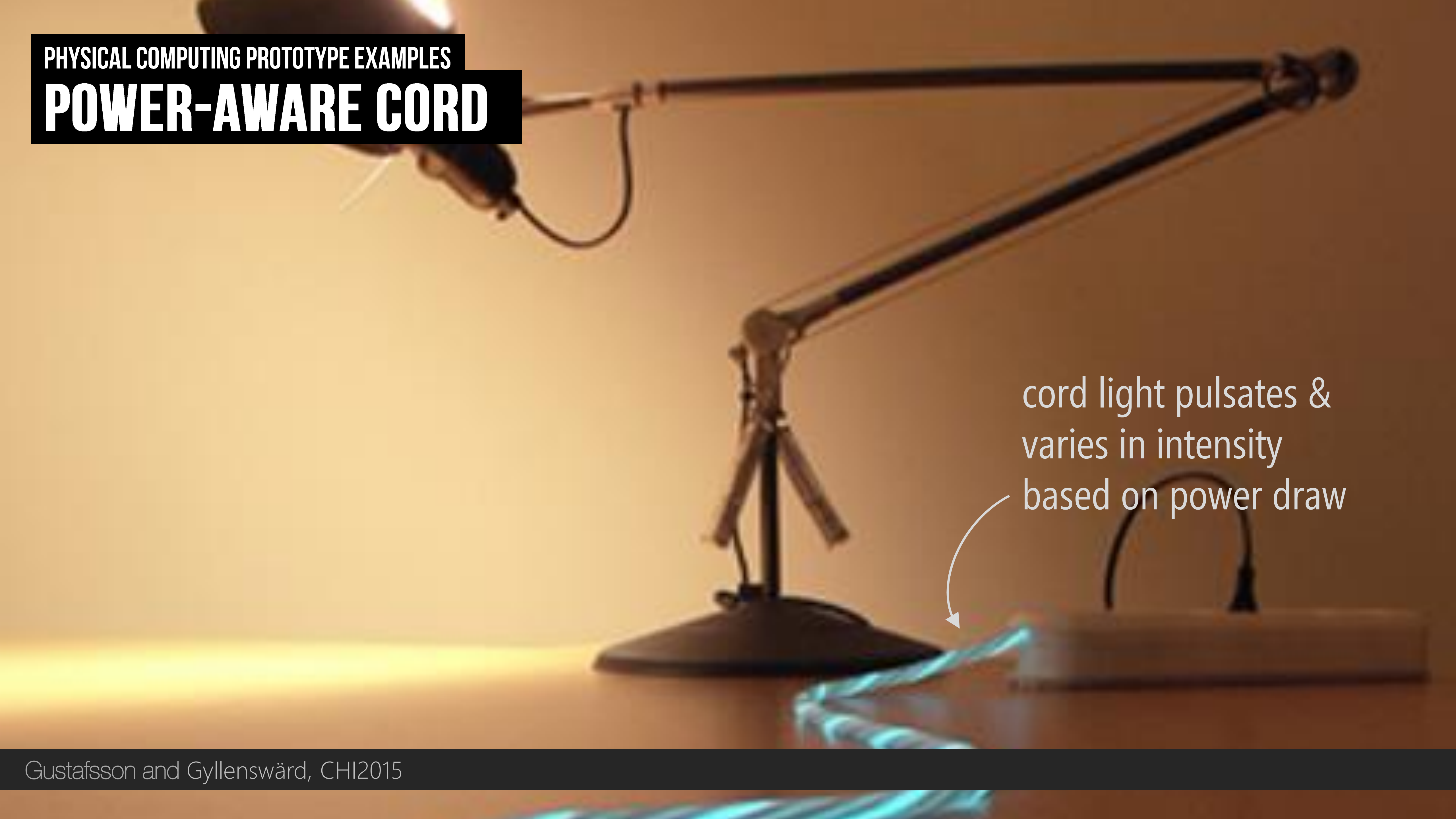
HEATSINK



Arroyo *et al.*, Waterbot: exploring feedback and persuasive techniques at the sink, *CHI'05*

PHYSICAL COMPUTING PROTOTYPE EXAMPLES

POWER-AWARE CORD



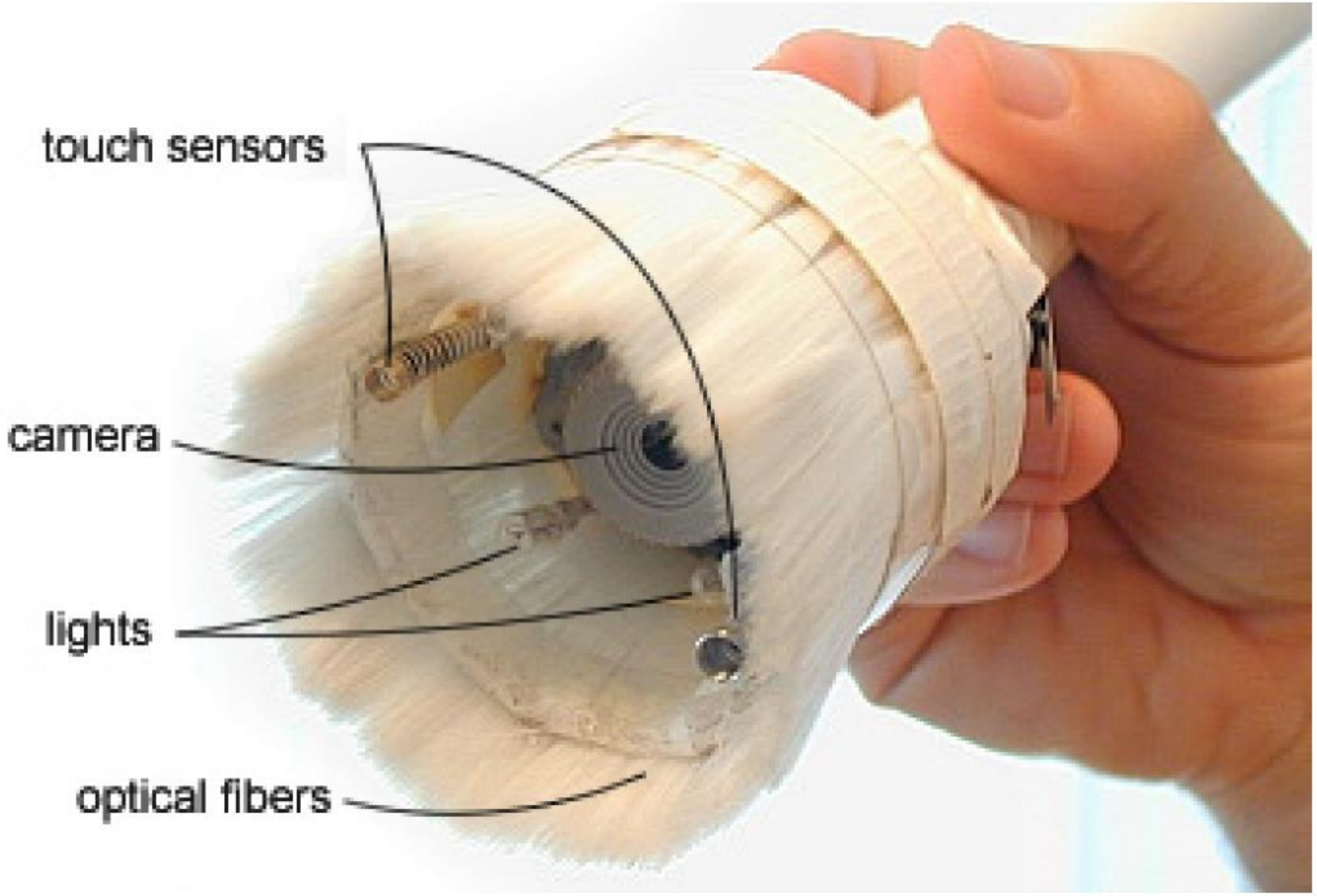
Gustafsson and Gyllenswärd, CHI2015

PHYSICAL COMPUTING PROTOTYPE EXAMPLES

I/O BRUSH: DRAWING WITH EVERYDAY OBJECTS

Ryokai *et al.*, I/O Brush: Drawing With Everyday Objects as Ink, CHI2004

I/O BRUSH: DRAWING WITH EVERYDAY OBJECTS



Ryokai *et al.*, I/O Brush: Drawing With Everyday Objects as Ink, CHI2004

PHYSICAL COMPUTING PROTOTYPE EXAMPLES

CUSTOM INPUT CONTROLLER: INTERACTIVE BEACH BALL

http://www.makeymakey.com/]

PHYSICAL COMPUTING PROTOTYPE EXAMPLES

INTERACTIVE WALL HANGING

Designers: Jie Qi & John Clifford, https://vimeo.com/40904471


蒲公英图

A3: Interactive IoT Night Light

A3 EXAMPLES

TINY CLOUD

Designer: Richard Clarkson, https://vimeo.com/111889143


100

A3: Interactive Nite Light

Published | Edit

Overview

Imagine working for a new "Internet of Things" (IoT) company that wants to make smart, interactive ambient lights including a new series of children's night lights, artistic home lighting, and even installations for public spaces (restaurants, atriums, etc.). In this assignment, you will build a new prototype IoT night light.

The night light must be controlled both through your Android phone (via Bluetooth) and through custom physical controls that you design. Your night light should also be encased in a custom lo-fi enclosure that you design and create (*e.g.*, using cardboard, paper, fabric, cotton balls, *etc.*). For your check-in next week, you must complete an initial version of the circuit and Arduino code to change the color of the light (using a mechanism of your choosing) and brightness (using a photosensitive resistor).

For your deliverables, you will turn in a video demo (like A1), all of your source code for both Arduino and Android + pictures of your circuit, your CAD files, and a short 1-page report (not including images) reporting on your design and key challenges/learnings.

Learning Goals

- Introduce and learn basics of electronic circuits, including voltage, current, and resistance
- Introduce and learn basic circuit design concepts, including voltage dividers, pull-up and pull-down resistors
- Introduce and learn the popular embedded prototyping platform Arduino (specifically, the RedBear Duo) and programming concepts therein
- Introduce and learn basic IoT concepts (*e.g.*, connecting to a device, I/O).

As with A1 & A2, we expect that you will seek out external sources to help you learn and complete this assignment. Please properly attribute your sources in your report (and in your code).

Parts

- [5 pts] **Circuit + physical controls**: Design your night light using an RGB LED. The individual color hues should be selectable via custom physical controls that you design (e.g., using trim POTs, using the force-sensitive resistor). The brightness of the LED should change automatically based on ambient light (inversely proportional to light level)
- [5 pts] **Smartphone app:** Design a simple Android-based smartphone app that allows you to select a color via touch (a manual color picker) and via the accelerometer/gyroscope.
- [2 pts] **Lo-fi enclosure:** Design a creative lo-fi enclosure that diffuses the LED (or LEDs) and exposes the controls and power.
- [2 pts] **Creative feature:** Add in a creative feature of your choice--this could be a new physical control, actuation (*e.g.*, LED affixed to servo), incorporating your step counter code (make the night light glow with each step), *etc.* Up to you. Be creative!

Deliverables

- [2 pts] Your **code** (either a github link or zipped and uploaded to Canvas). Your code should follow software engineering best practices and be formatted for readability. Any code that is informed by or copied from the Internet (or other sources) **must** be properly commented with an attribution link back to the source. If you hosted your code on github (or some other online repo), please include a link to it in your report.
- [2 pts] A brief, **1-page report** that: (i) provides an overview of your night light; (ii) describes your creative feature; (iii) enumerates key struggles and challenges; (v) reflects on what you learned. You should include as many images as you want (at least one) that helps explain your night light. Images are free. You need not write in prose (you can bullet point the entire report).
- [2 pts] A brief (2 mins or less) **video overview of your night light** posted to YouTube, which walks us through each of the required parts of the assignment. This can and should be super casual, no editing is necessary. You can use your laptop camera or an additional smartphone for recording. The YouTube video can be unlisted or public (your choice). Please include a link to this video in your report.

Breadboard/Sensor Kits for Each Student in Class

Received date		Need By	Cost	Count Per Student	Overall Count
4/9/2018	RedBear Duo with headers soldered on	April 18, 2018	$22.50	1	42
4/16/2018	Ultrasonic Sensor	May 9, 2018	$3.75	1	42
4/16/2018	Quad Level-Shifter 3V - 5V	April 18, 2018	$1.35	1	42
4/16/2018	Force-Sensitive Resistor	April 18, 2018	$6.30	1	42
4/16/2018	IMU	May 9, 2018	$13.46	1	42
4/16/2018	Potentiometers 10K	April 18, 2018	$0.86	3	126
4/16/2018	10K Resistors (25 Pack)	April 18, 2018	$0.68	1	42
4/16/2018	Slide potentiometer (10k)	April 18, 2018	$1.85	1	42
4/16/2018	2.2K Resistors (25 Pack)	April 18, 2018	$0.68	1	42
4/16/2018	Full breadboard	April 18, 2018	$5.36	1	42
4/16/2018	Mini breadboard	April 18, 2018	$4.50	1	42
4/16/2018	Photocell	April 18, 2018	$0.86	1	42
4/16/2018	Ball tilt sensor	May 9, 2018	$1.85	1	42
4/12/2018	Piezo buzzer	May 9, 2018	$0.62	1	42
4/16/2018	RGB LEDs	April 18, 2018	$1.50	2	84
4/16/2018	Red LEDs (25 Pack)	April 18, 2018	$3.60	1	42
4/16/2018	Jumper Wire	April 18, 2018	$4.46	1	42
4/16/2018	Binary Hall Effect Sensor	April 18, 2018	$1.75	1	42
4/16/2018	Micro servo	May 9, 2018	$5.36	1	42
4/16/2018	Tactile Switch Buttons	April 18, 2018	$2.25	1	42
4/12/2018	3xAAA Battery Holder	May 9, 2018	$1.95	1	42

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INTRODUCTION TO CIRCUITS: LEARNING GOALS

What is a **circuit** and what is Ohm's Law

What is a **multimeter** and how to use it

What is a **breadboard** and how to use it

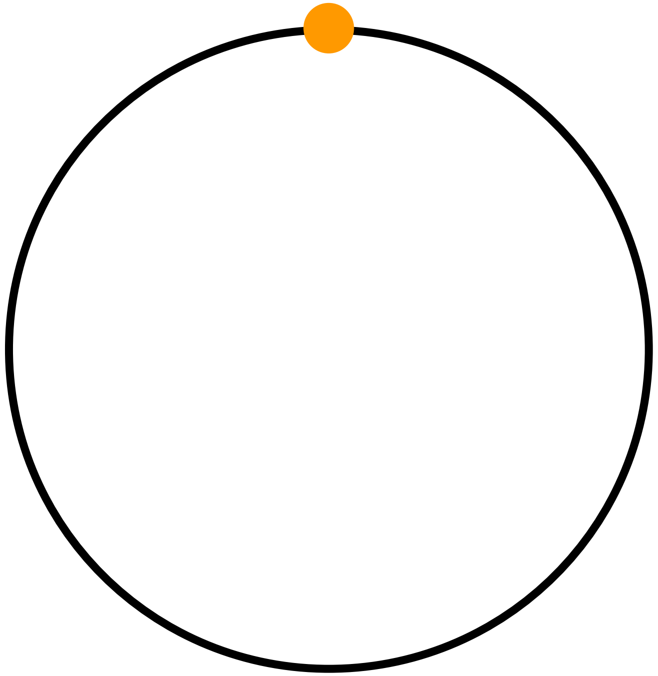
What is a **resistor** and how to use it

What is an **LED** and how to use it (*e.g.*, polarity, current limiting resistor)

How to **read a datasheet**

WHAT IS A CIRCUIT?

WHAT IS A CIRCUIT?



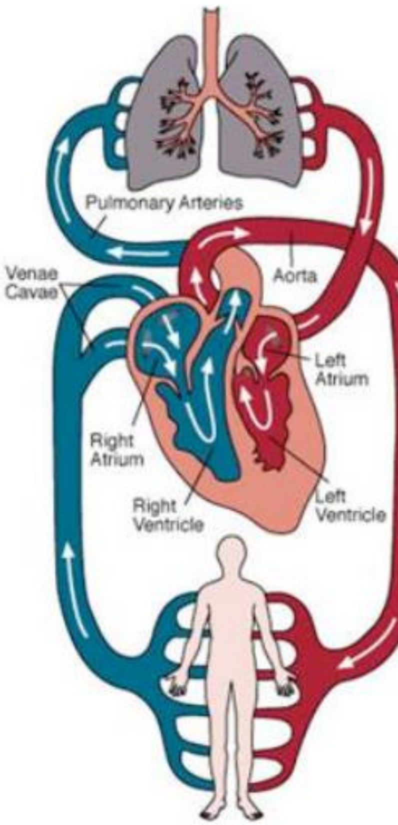
cir·cut [noun]

A route that starts and finishes at the same place.

- Oxford Dictionary

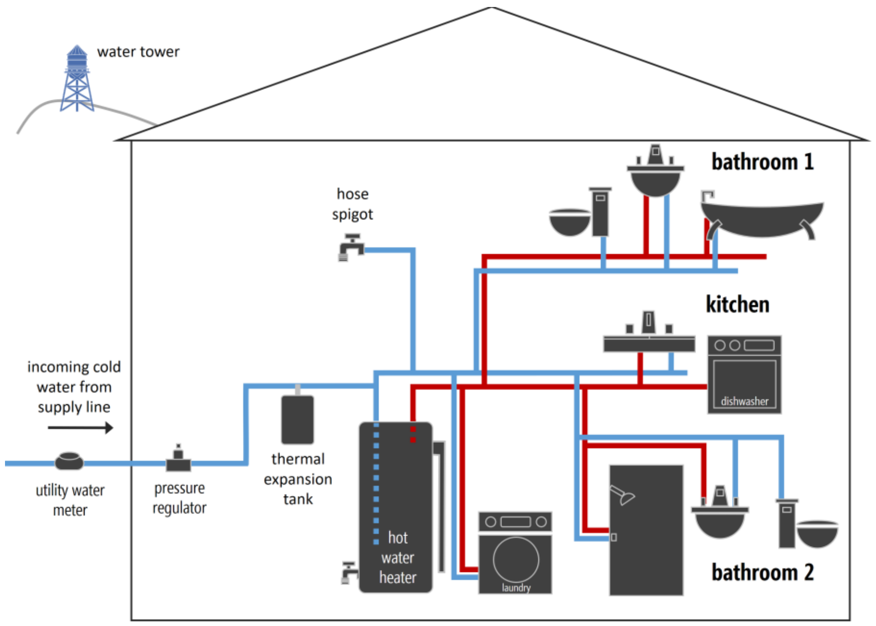
SOME EXAMPLE CIRCUITS

HUMAN CIRCULATORY SYSTEM



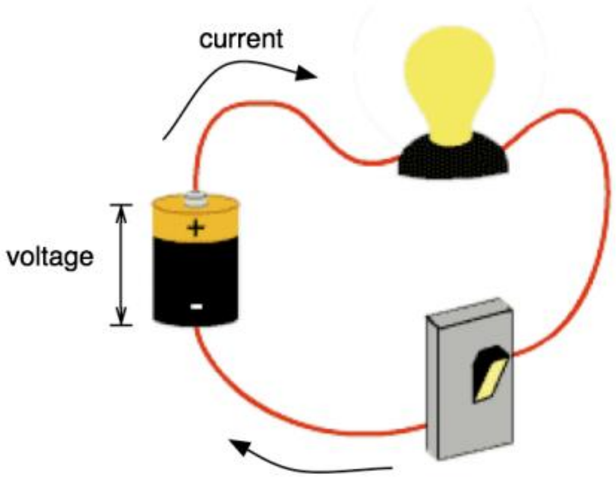
Heart pumps, blood flows

WATER PLUMBING SYSTEM



Water pressure pushes, water flows

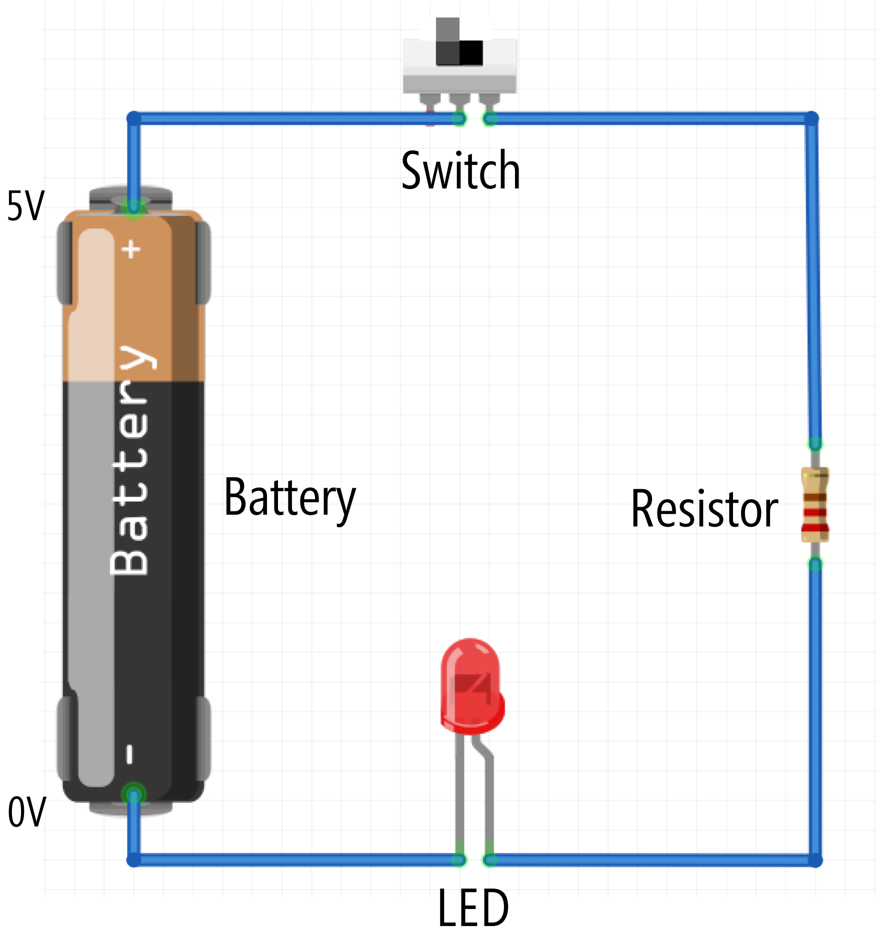
ELECTRICAL CIRCUITS

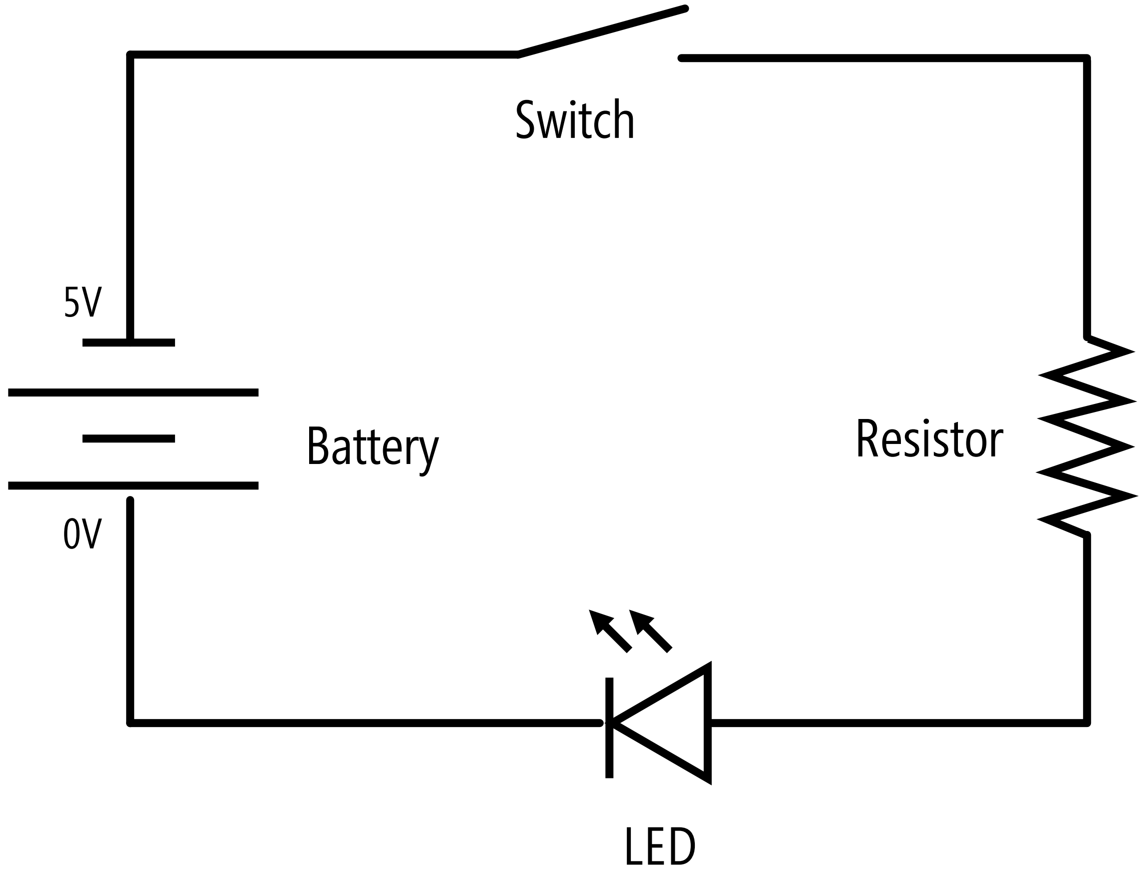


Voltage pushes, current flows

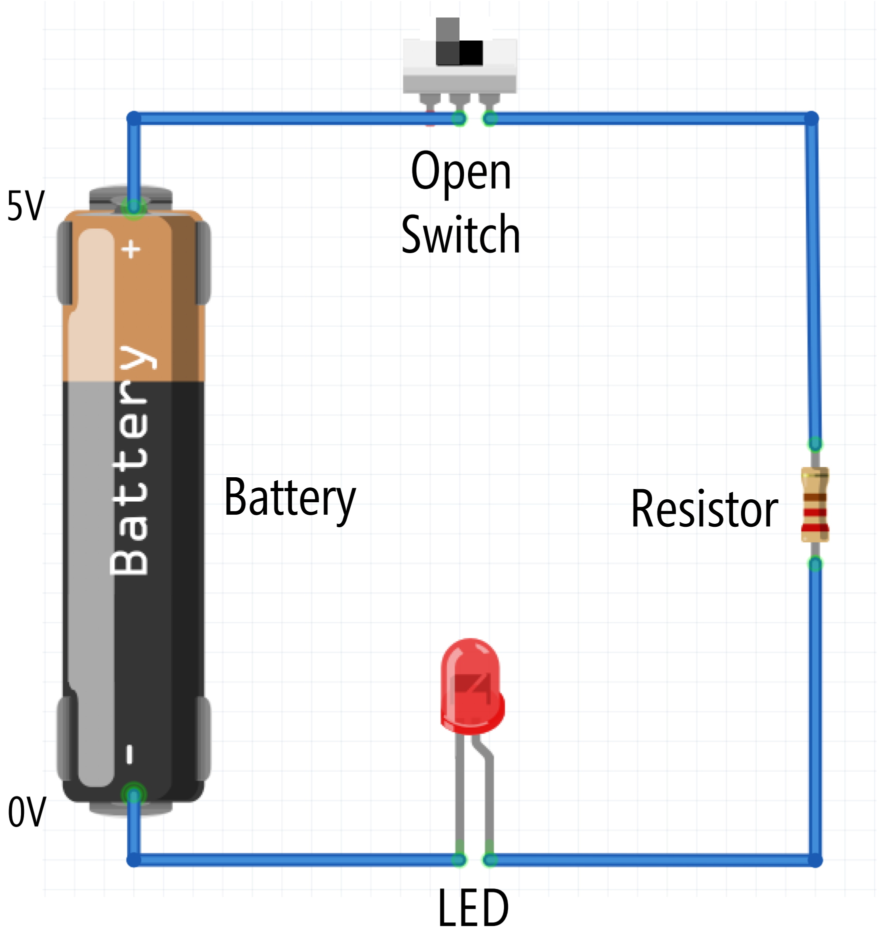
Based on: http://todbot.com.s3.amazonaws.com/spookyarduino/arduino_spooky_projects_class1.pdf

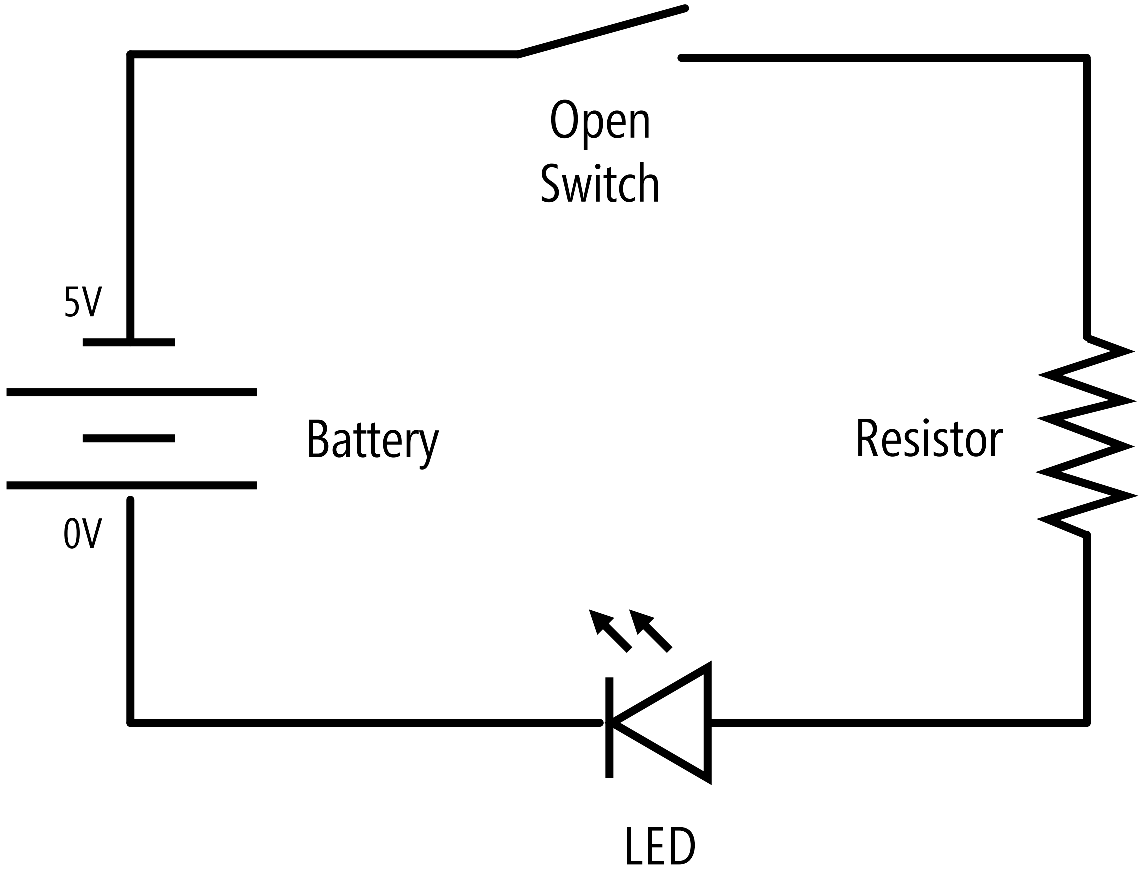
PICTORIAL VS. SCHEMATIC CIRCUIT DIAGRAMS



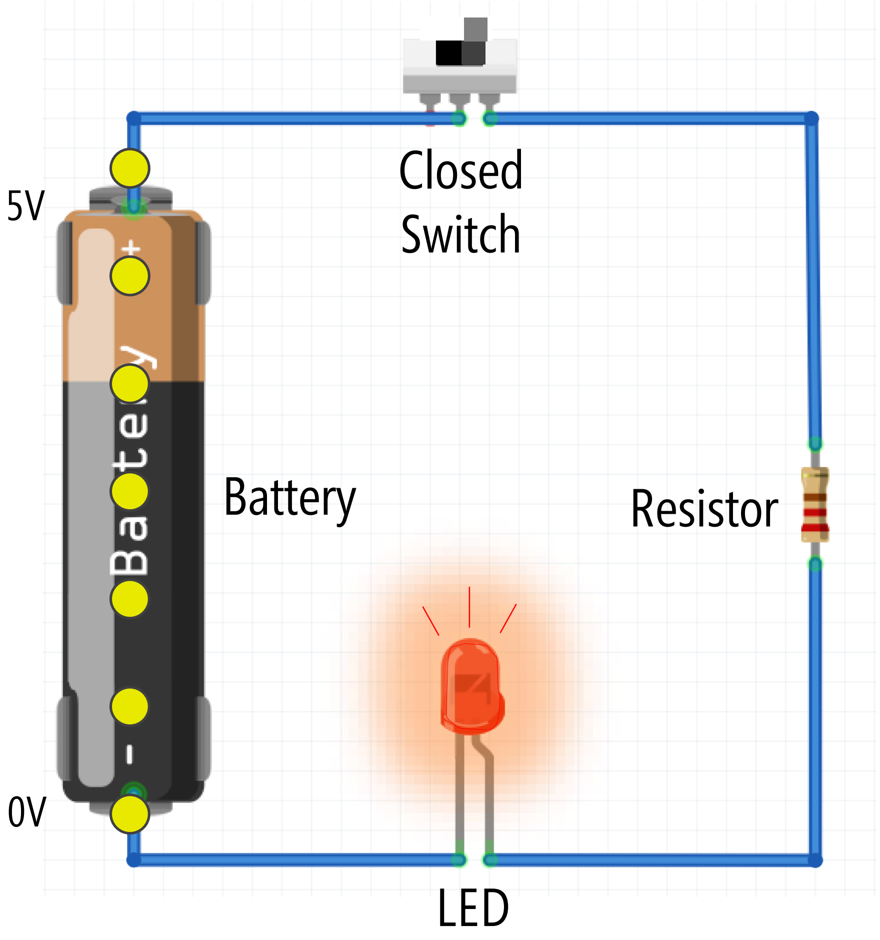


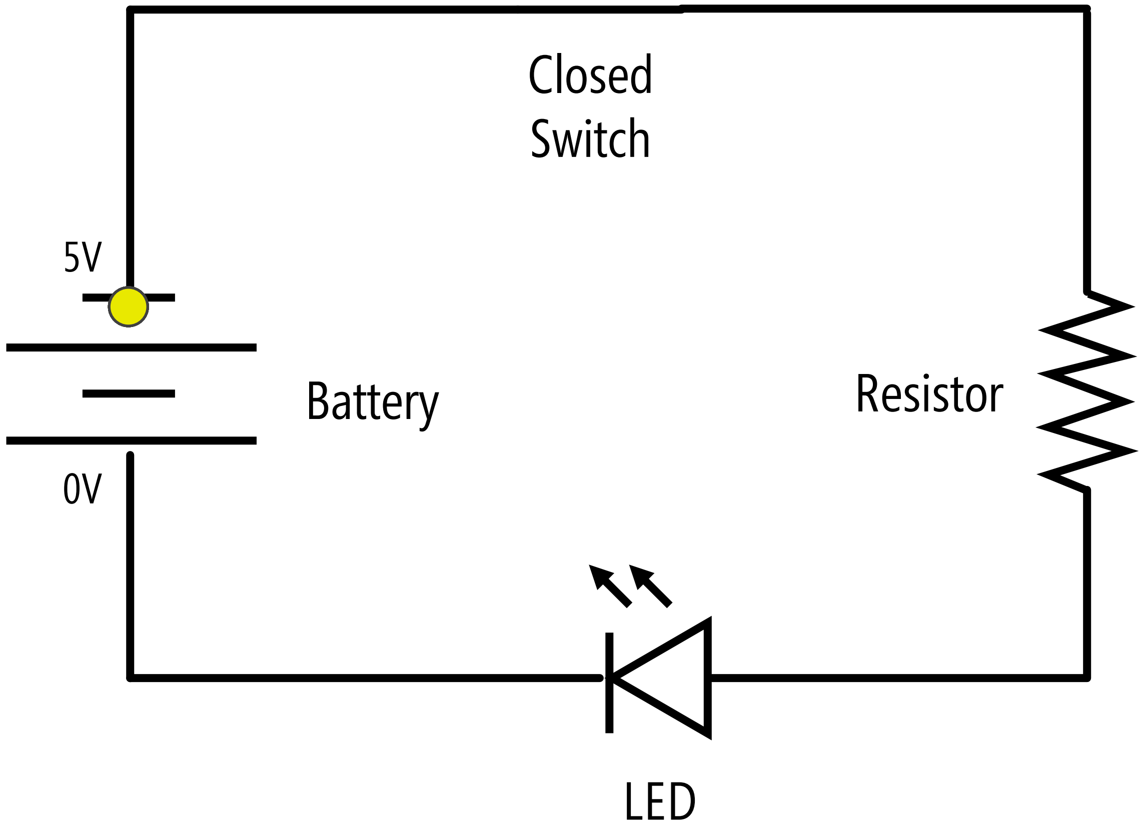
OPEN CIRCUIT: NO CURRENT FLOWING





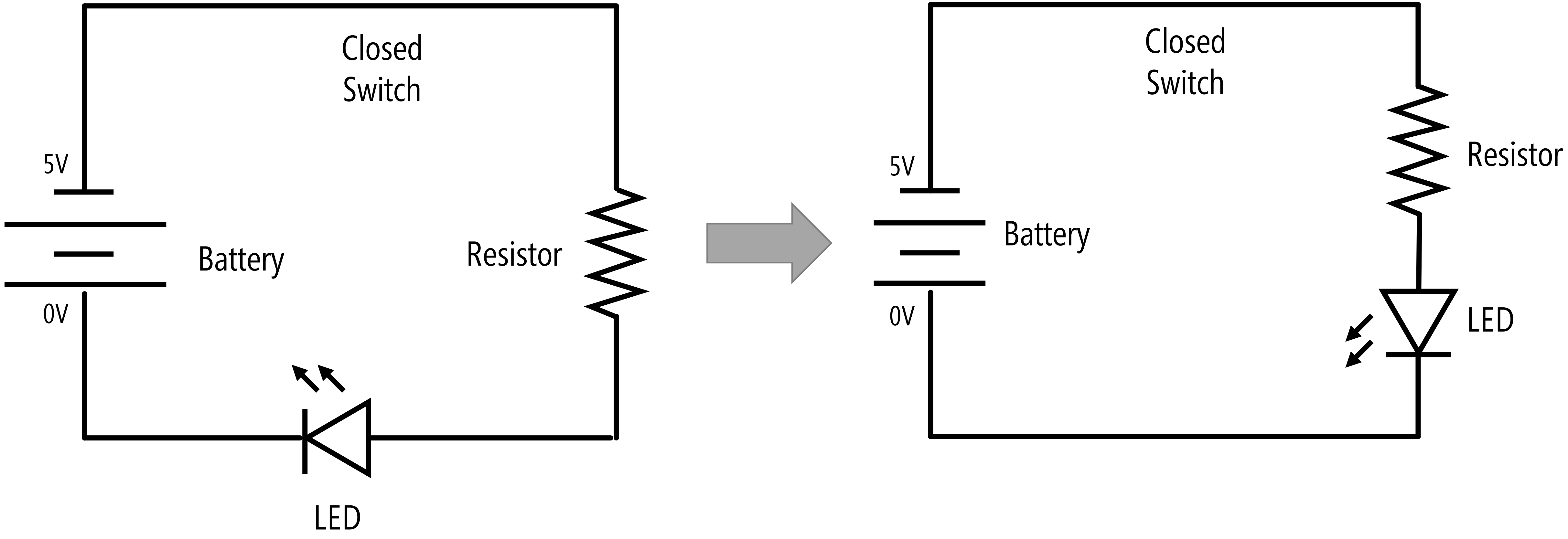
CLOSED CIRCUIT: CURRENT FLOWING





REARRANGE CIRCUIT

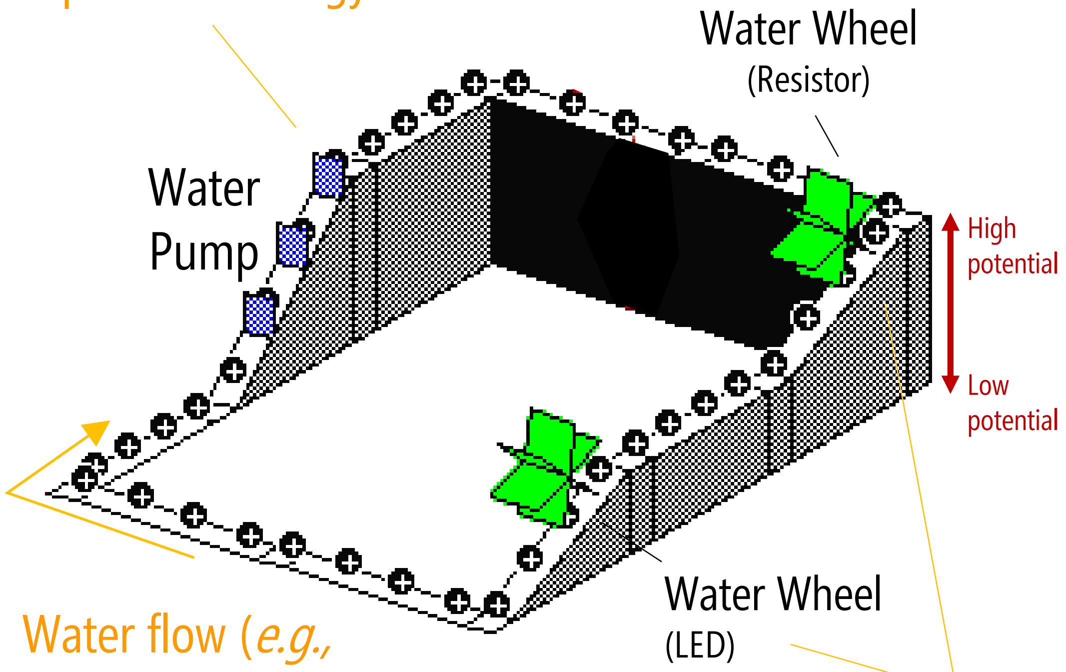
Both circuits are equivalent

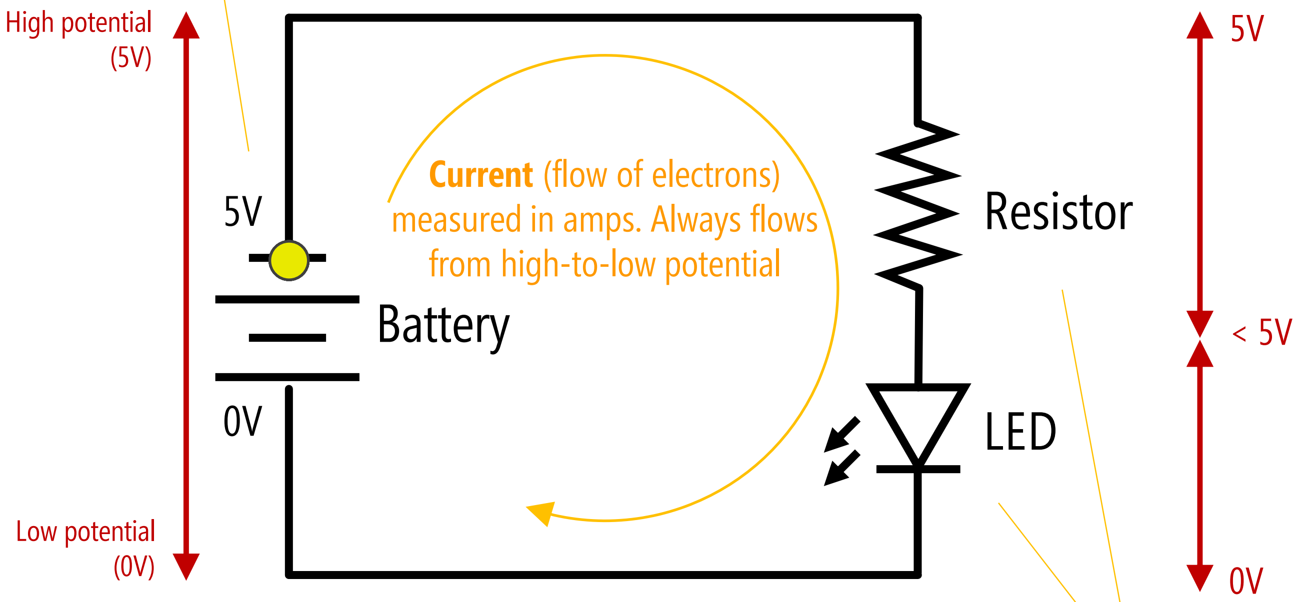


ELECTRIC CIRCUITS: WATER ANALOGY

Water pump increases potential energy

Battery provides force to move electrons (measured in **voltage**)



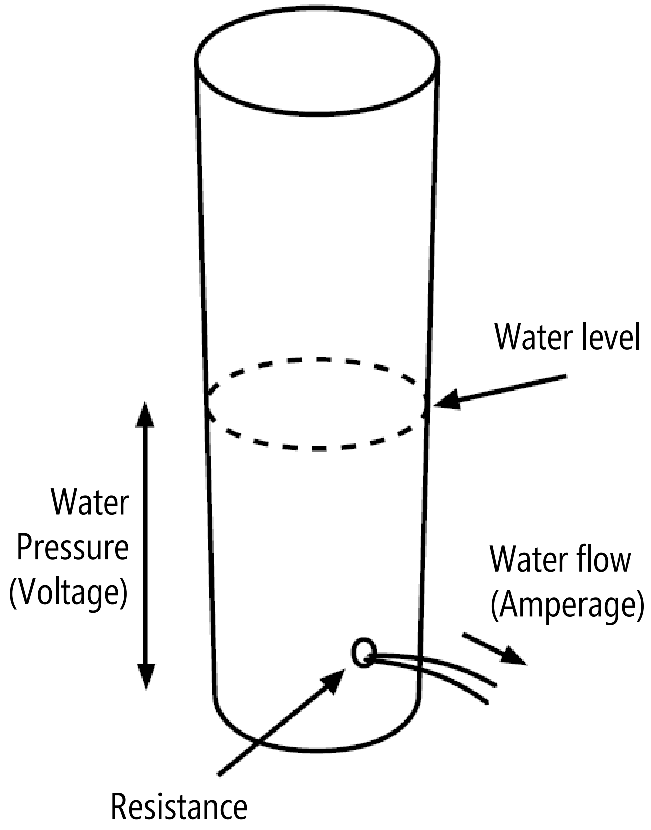


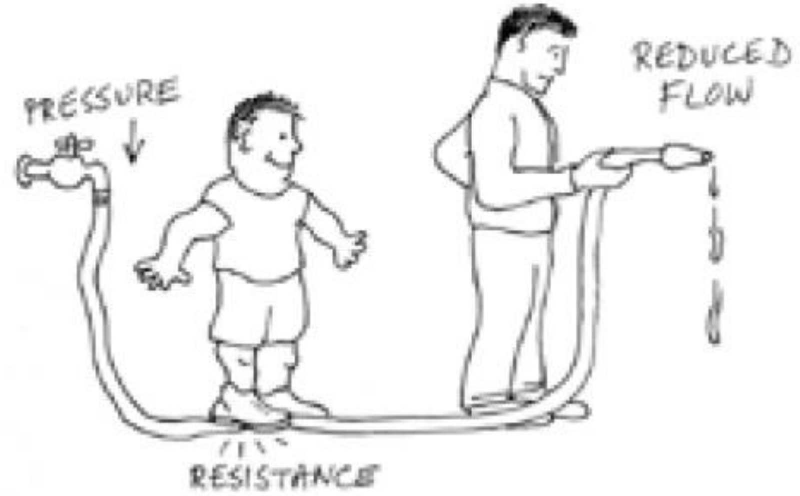
Water flow (*e.g.,* gallons/min). Always flows from high-to-low potential.

Water turning wheel takes work thus reducing force

Resistor and LED use energy (as heat & light), which reduces **voltage**

ELECTRIC CIRCUITS: WATER ANALOGY 2

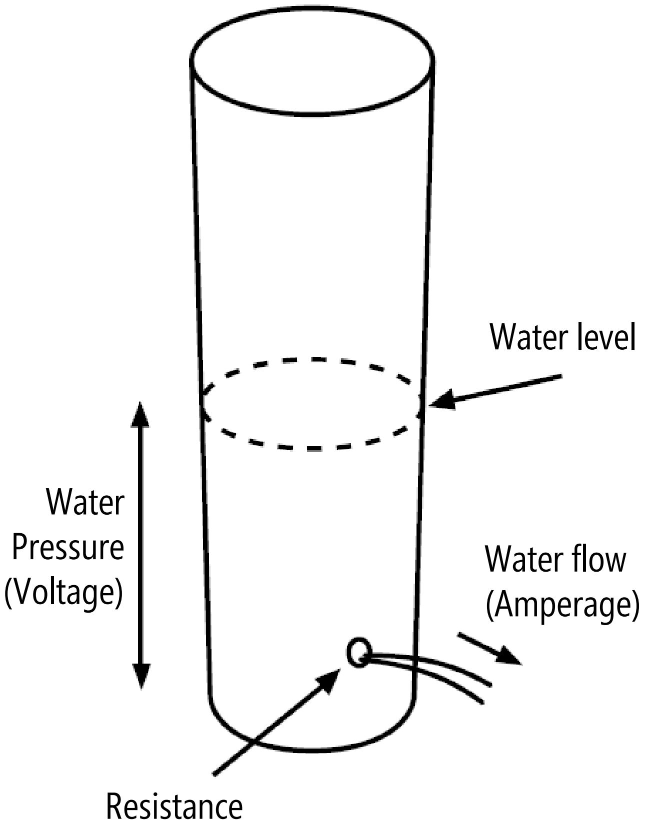


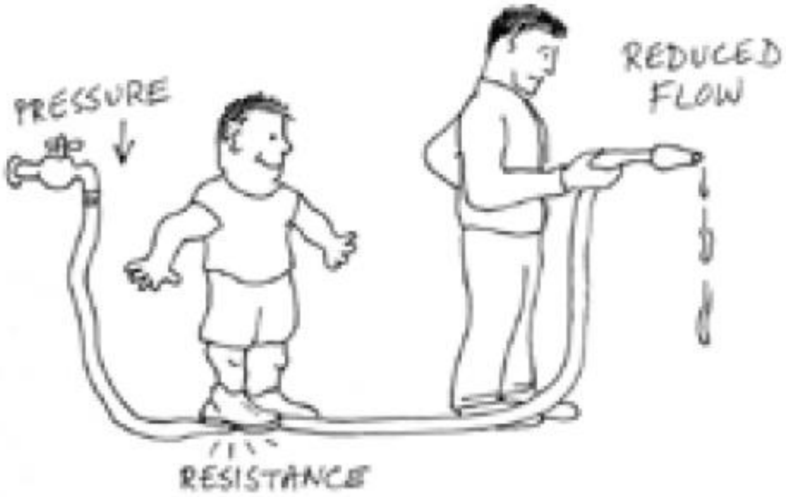


Increase resistance, reduce flow

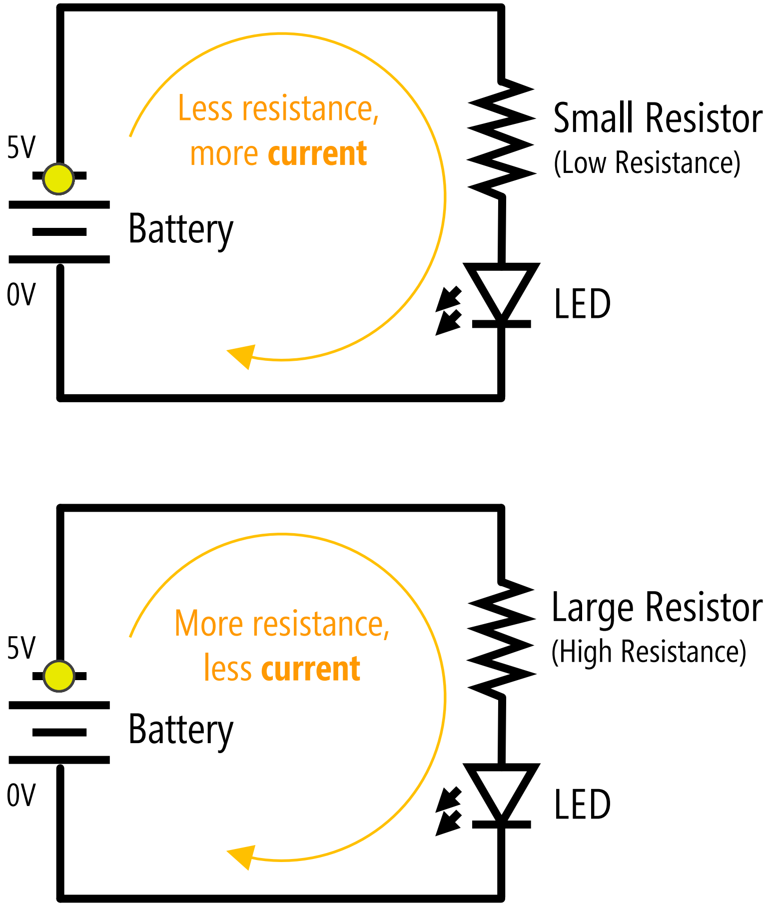
Based on: Platt, Make: Electronics, 1st Edition

ELECTRIC CIRCUITS: WATER ANALOGY 2





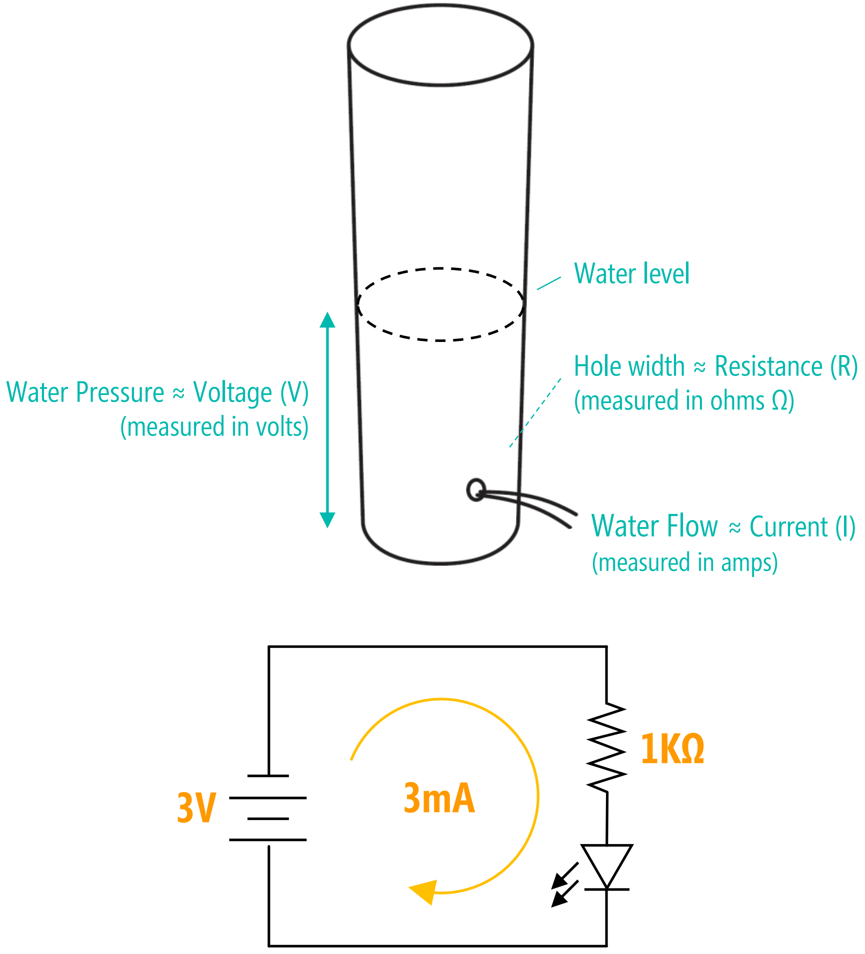
Increase resistance, reduce flow



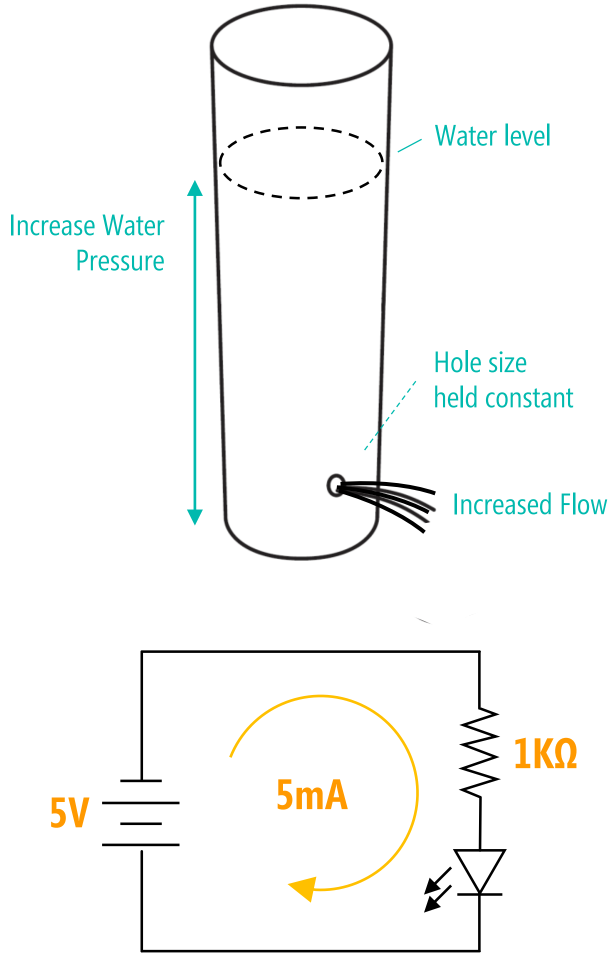
Based on: Platt, Make: Electronics, 1st Edition

TWO WAYS TO INCREASE CURRENT

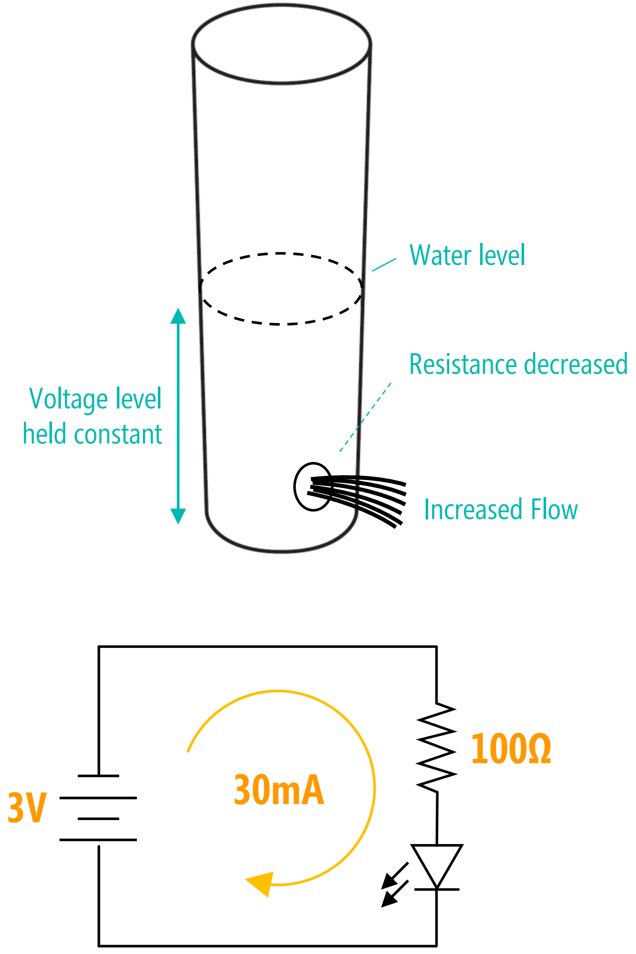
Base Circuit



Increase Voltage



Decrease Resistance

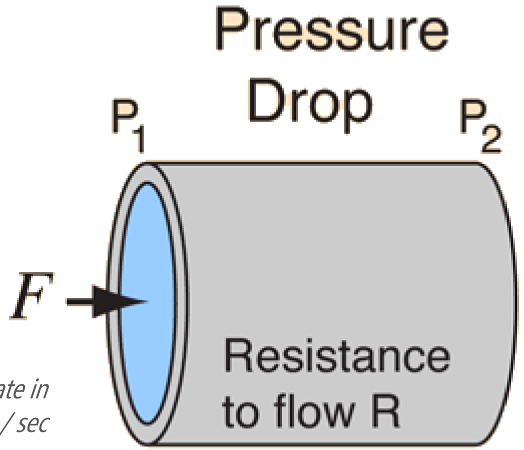


Based on figures from: Platt, Make: Electronics, 1st Edition

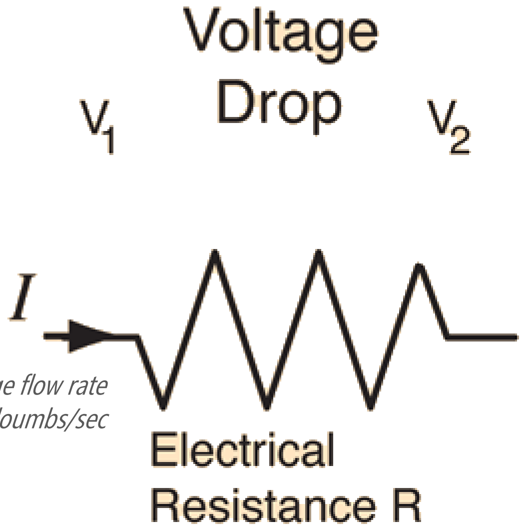
But how do we know how much current is flowing through our circuit?

OHM'S LAW

Current is linearly proportional to the amount of voltage and resistance in circuit



F = flow rate in cm^3 / sec



I = charge flow rate in coloumbs/sec

$$F = \frac{P_1 - P_2}{R}$$

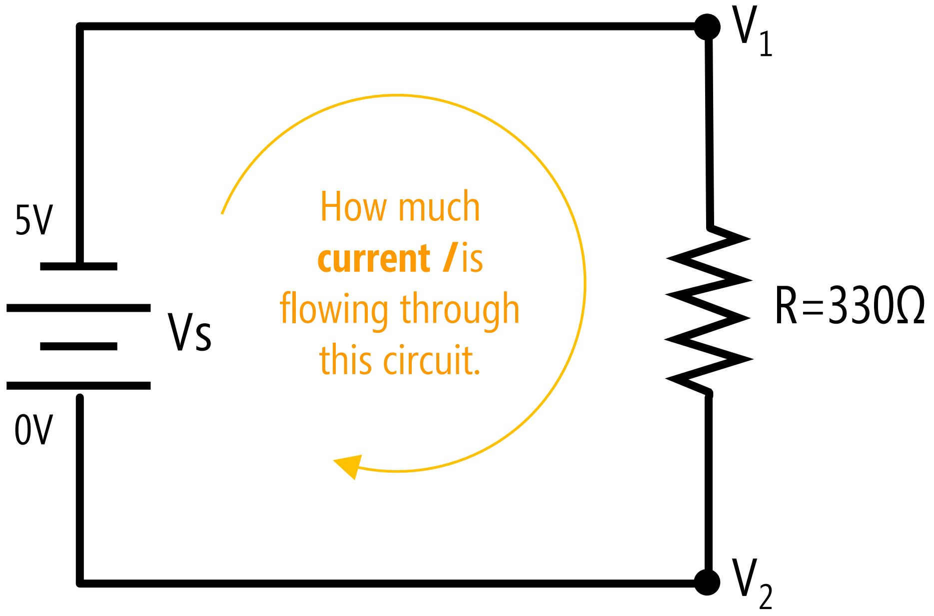
Poiseuille's Law for fluids

$$I = \frac{V_1 - V_2}{R}$$

Ohm's Law for electric circuits

Based on: Scherz & Monk, Practical Electronics for Inventors, 3rd Edition; http://en.wikipedia.org/wiki/Hagen%E2%80%93Poiseuille_equation; http://hyperphysics.phy-astr.gsu.edu/hbase/electric/watcir2.html

OHM'S LAW EXERCISE: SOLVE FOR CURRENT

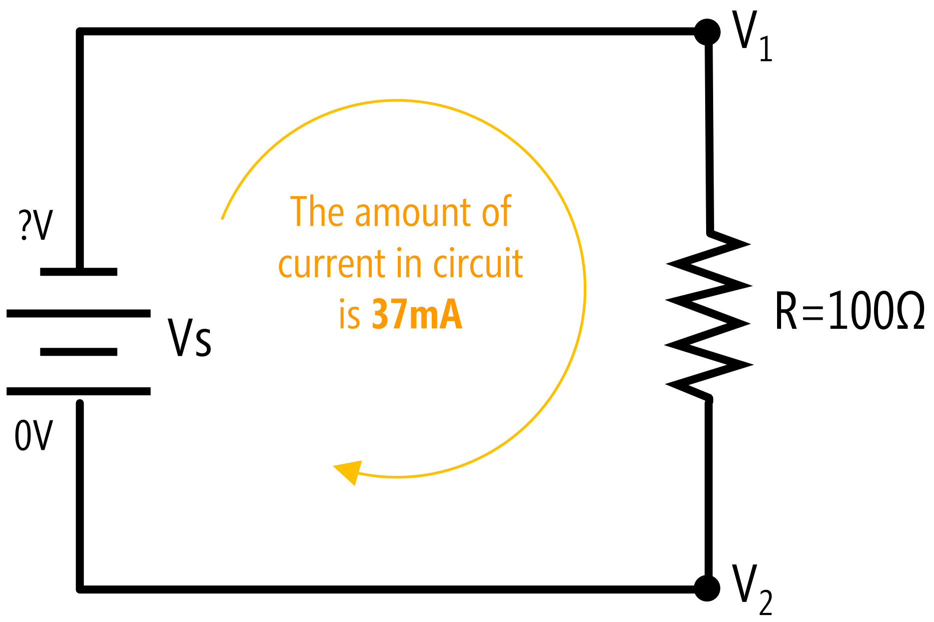


$$Current = I = \frac{V_{high\,potential} - Vlow_{\,potential}}{R}$$

$$Current = I = \frac{5V - 0V}{330\Omega}$$

$$Current = I = 0.015A = 15mA$$

OHM'S LAW EXERCISE: SOLVE FOR VOLTAGE

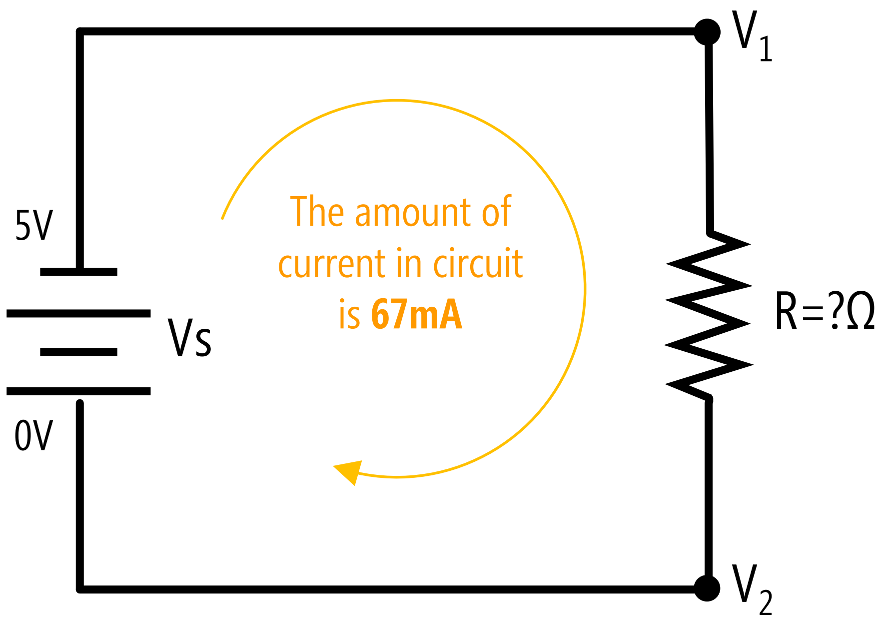


$$Current = I = \frac{V_{high\,potential} - Vlow_{\,potential}}{R}$$

$$Voltage = V = I \, * R$$

$$Voltage = V = 0.037A \, * 100\Omega = 3.7V$$

OHM'S LAW EXERCISE: SOLVE FOR RESISTANCE



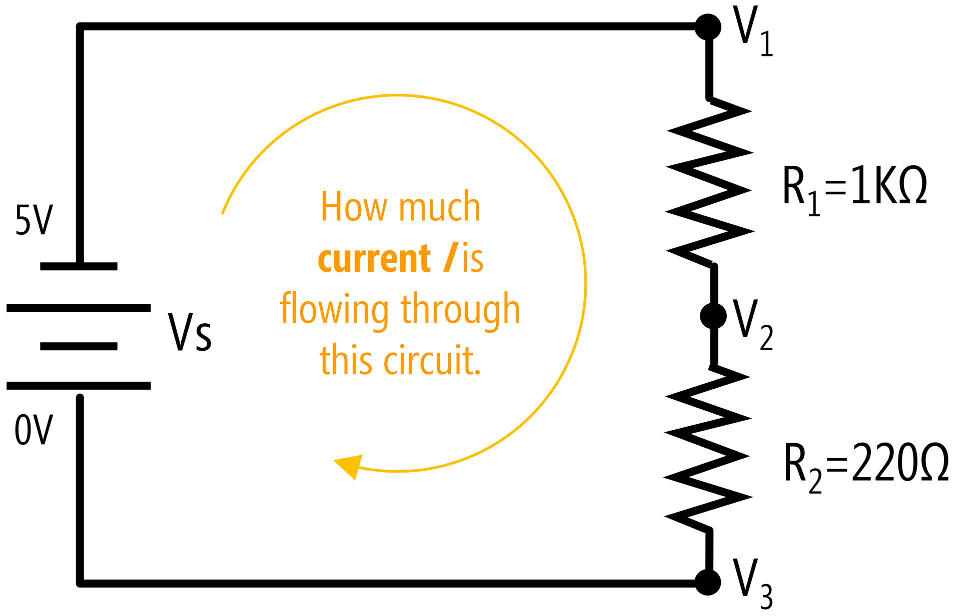
$$Current = I = \frac{V_{high\,potential} - Vlow_{\,potential}}{R}$$

$$Resistance = R = \frac{V}{I}$$

$$Resistance = R = \frac{5V}{0.067A} = 74.6\Omega$$

OHM'S LAW EXERCISE: RESISTORS IN SERIES

We sum resistors in series. Solve for current.



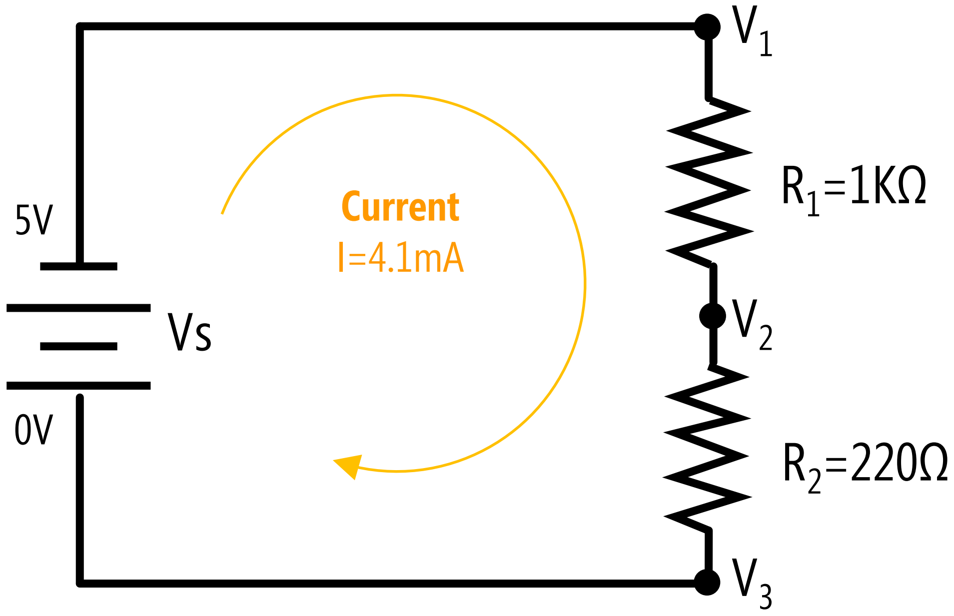
$$Current = I = \frac{V_{high\,potential} - Vlow_{potential}}{R_1 + R_2}$$

$$Current = I = \frac{5V - 0V}{1{,}220\Omega}$$

$$Current = I = 0.0041A = 4.1mA$$

OHM'S LAW EXERCISE: SOLVE FOR V1, V2, AND V3

How would you calculate the voltage drop over R_1?



$$Current = I = \frac{V_{high\,potential} - Vlow_{potential}}{R}$$

$$V_1 - V_2 = I * R_1$$

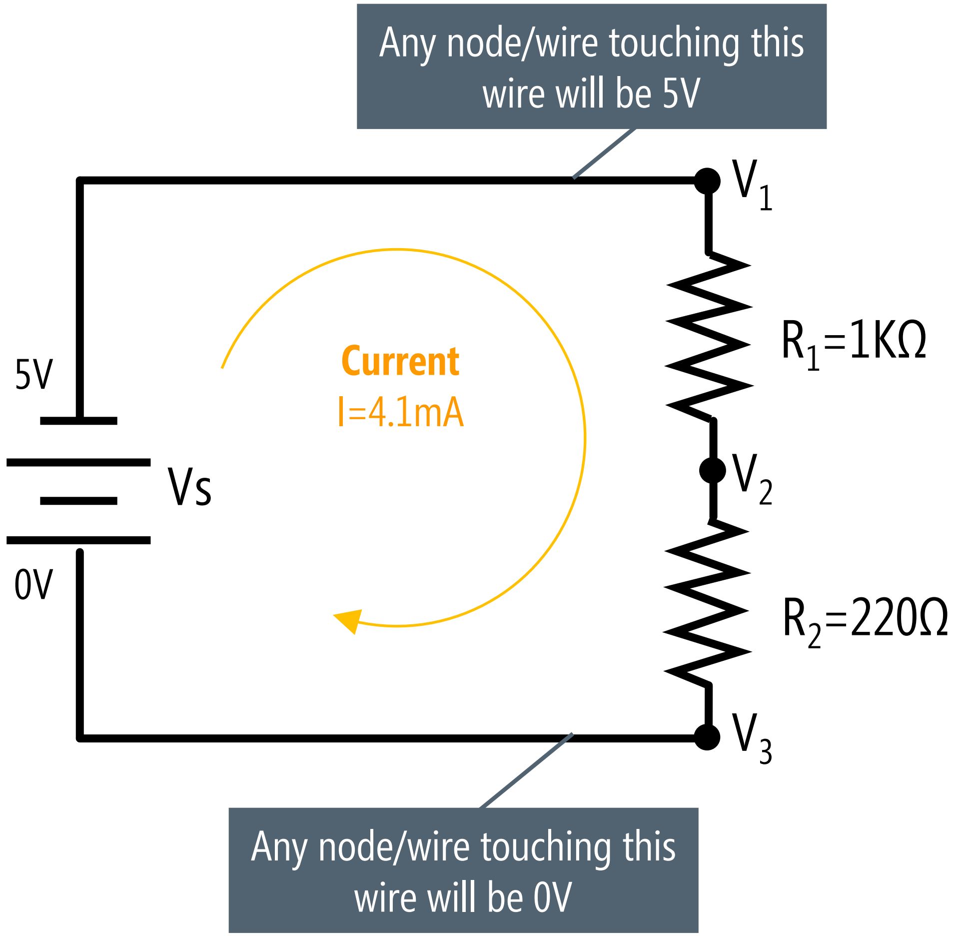
$$V_2 = V_1 - I * R_1$$ And we know $V_1 = 5V$

$$V_2 = 5V - 0.0041A * 1{,}000\Omega = 0.9\mathrm{V}$$

$$V_3 = 0V$$

OHM'S LAW EXERCISE: SOLVE FOR V1, V2, AND V3

How did I know V1 and V3?



$$Current = I = \frac{V_{high\,potential} - Vlow_{potential}}{R}$$

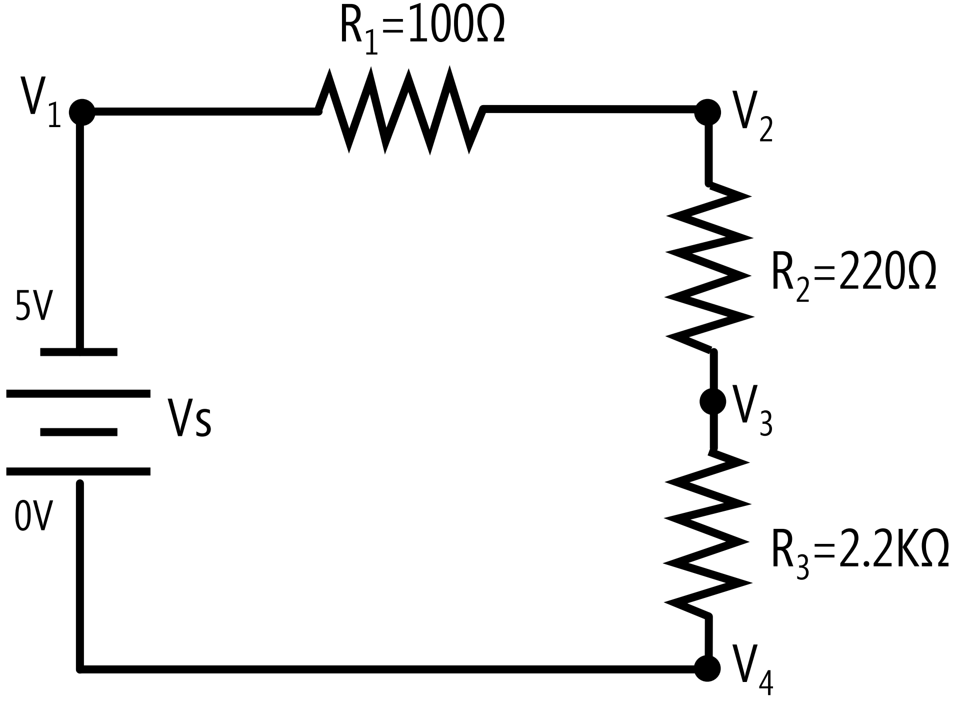
$$V_1 - V_2 = I * R_1$$

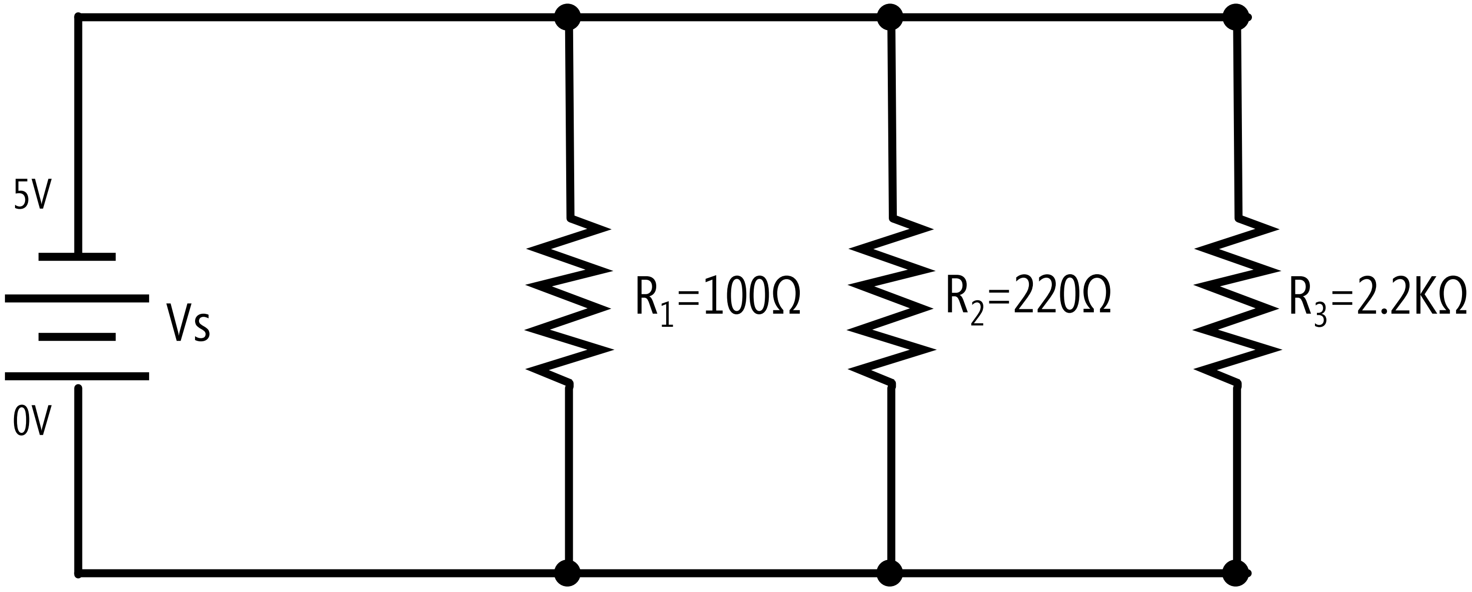
$$V_2 = V_1 - I * R_1$$ And we know $V_1 = 5V$

$$V_2 = 5V - 0.0041A * 1{,}000\Omega = 0.9\text{V}$$

$$V_3 = 0V$$

SERIES VS. PARALLEL

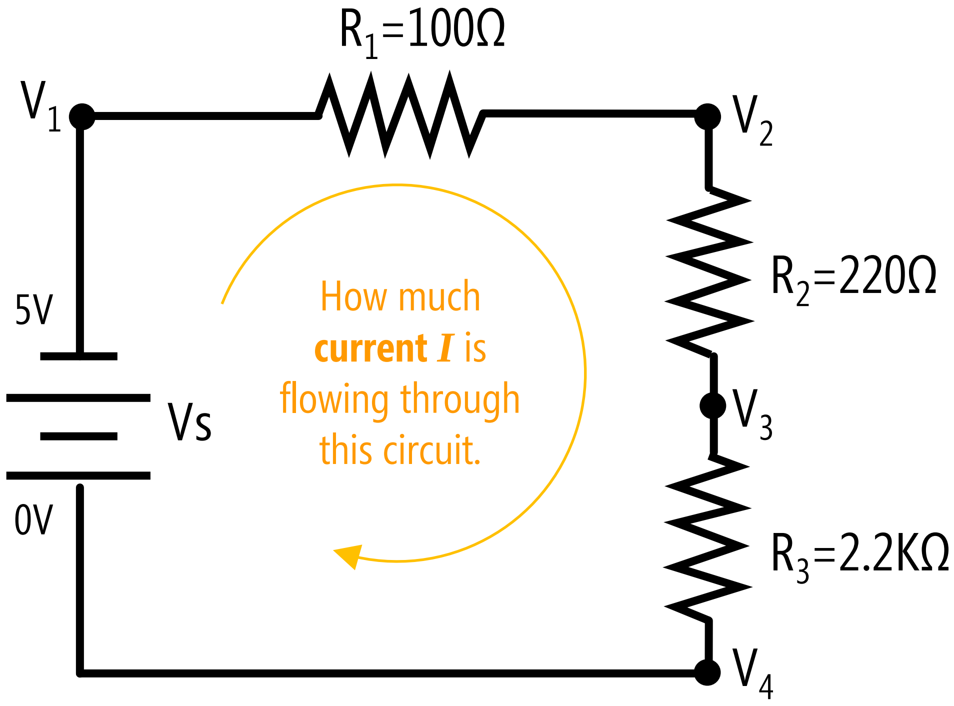


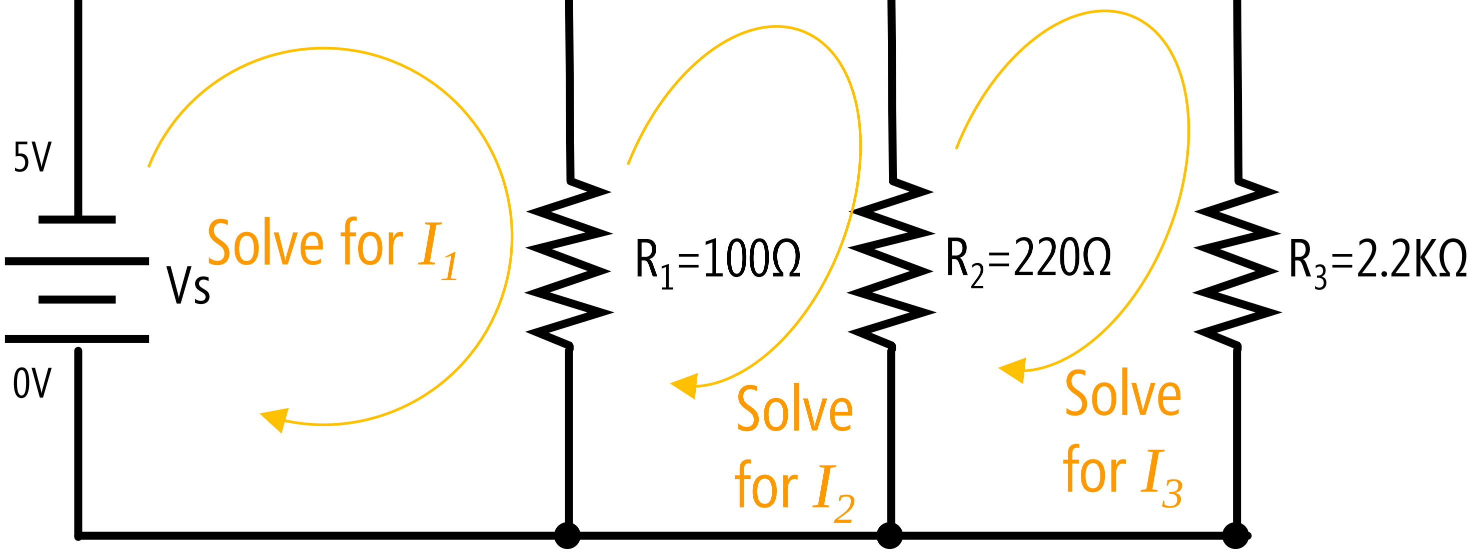


Resistors in Series
Although there is a voltage drop across each resistor, there is only one path for the current to flow, so there is one current I value for the entire circuit.

Resistors in Parallel
Here, there are **three** potential branches for current to flow. The amount of current across each branch is dependent on the resistance values.

SERIES VS. PARALLEL





Resistors in Series
Although there is a voltage drop across each resistor, there is only one path for the current to flow.

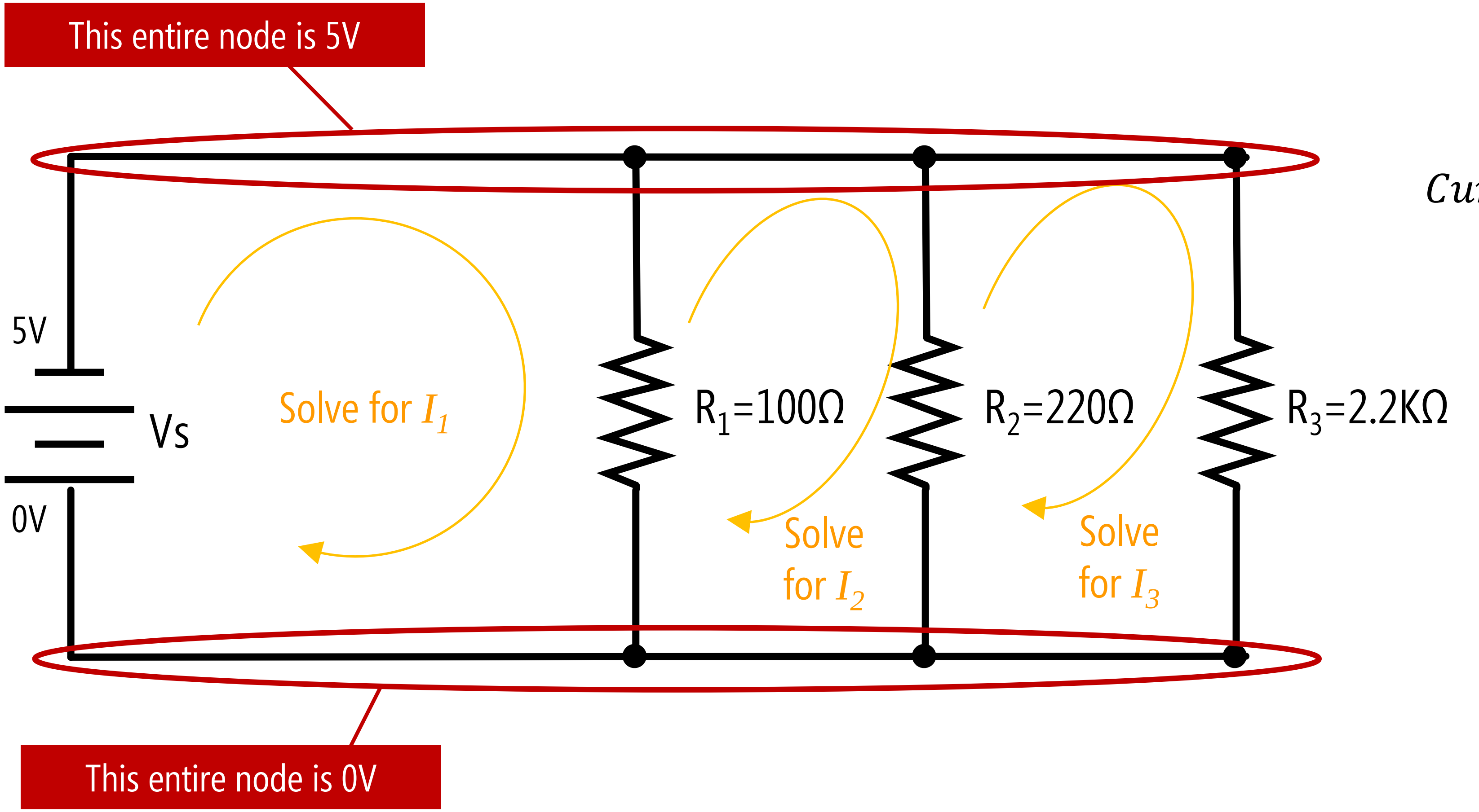
$$I_{total} = \frac{V_{high\ potential} - Vlow_{\ potential}}{R_1 + R_2 + R_3}$$

Resistors in Parallel
Here, there are **three** potential branches for current to flow. The amount of current across each branch is dependent on the resistance values.

$$I_{total} = I_1 + I_2 + I_3 = ?$$

OHM'S LAW EXERCISE: RESISTORS IN PARALLEL

How much current travels down each path? And what is I_{total}



$$Current = I = \frac{V_{high\,potential} - Vlow_{potential}}{R}$$

$$I_1 =$$

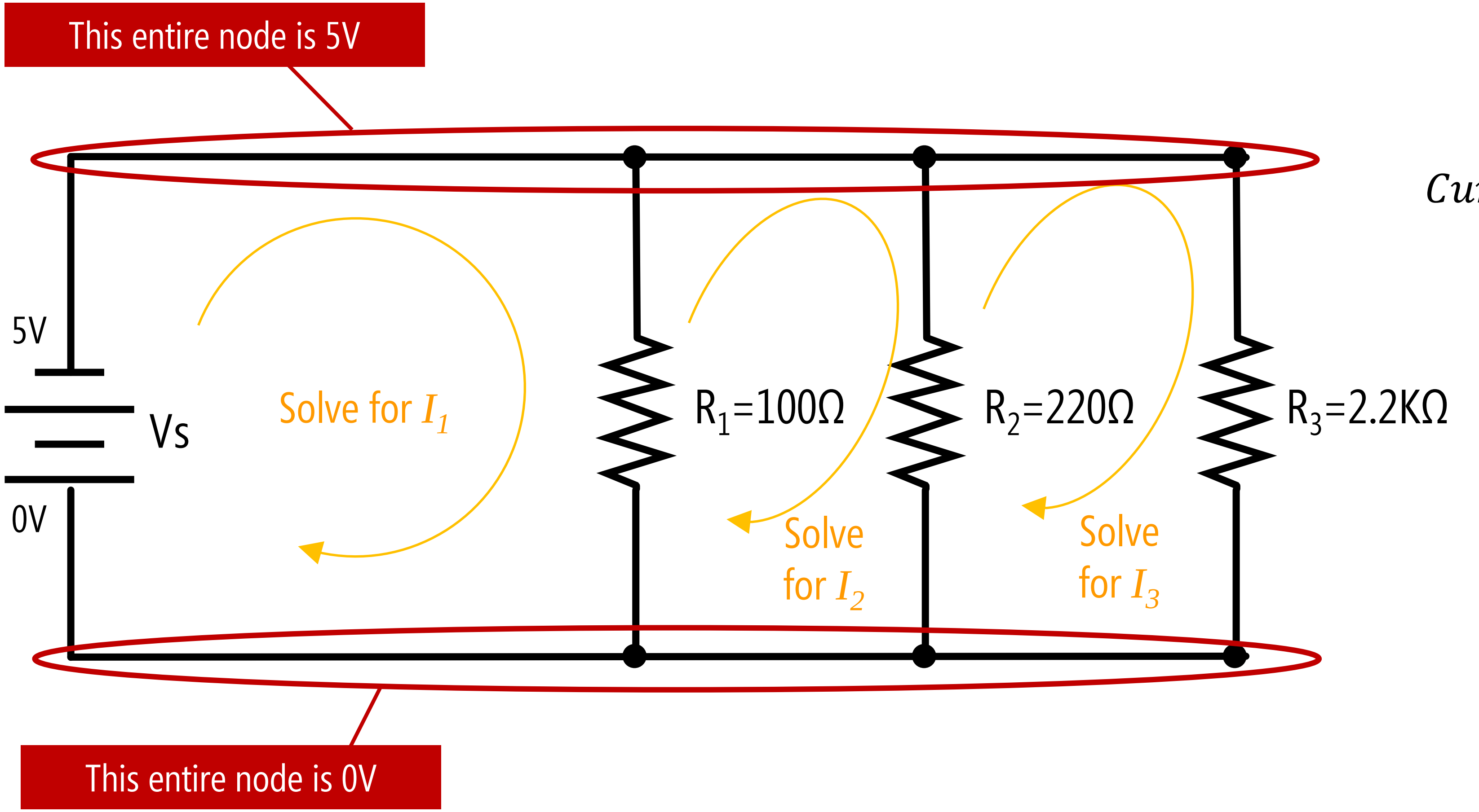
$$I_2 =$$

$$I_3 =$$

$$I_{Total} = I_1 + I_2 + I_3 =$$

OHM'S LAW EXERCISE: RESISTORS IN PARALLEL

How much current travels down each path? And what is I_{total}



$$Current = I = \frac{V_{high\ potential} - Vlow_{\ potential}}{R}$$

$$I_1 = \frac{5V - 0V}{100} = 50mA$$

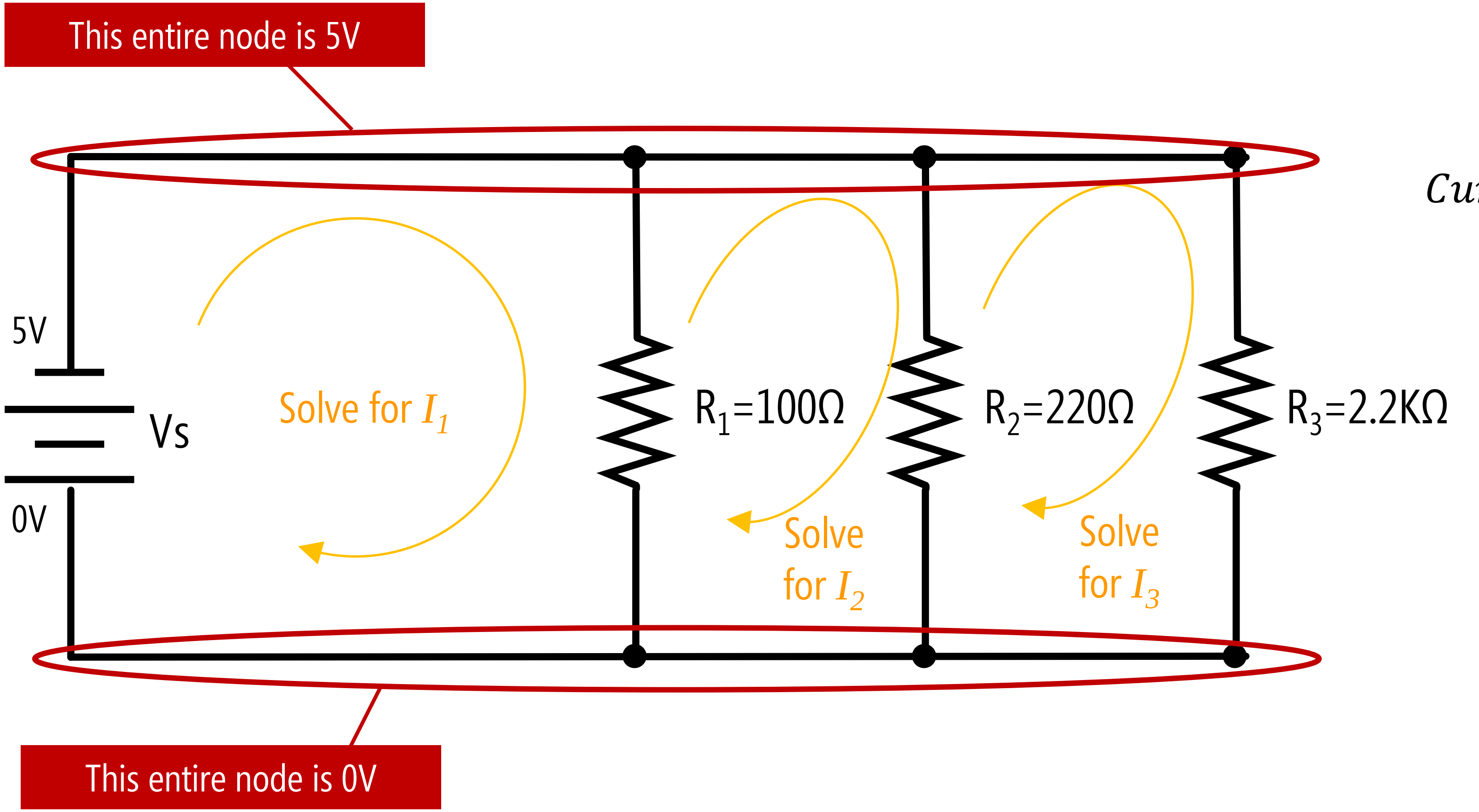
$$I_2 =$$

$$I_3 =$$

$$I_{Total} = I_1 + I_2 + I_3 = \sim 75\text{mA}$$

OHM'S LAW EXERCISE: RESISTORS IN PARALLEL

How much current travels down each path? And what is I_{total}



$$Current = I = \frac{V_{high\,potential} - Vlow_{potential}}{R}$$

$$I_1 = \frac{5V - 0V}{100} = 50mA$$

$$I_2 = \frac{5V - 0V}{220} = 22.7mA$$

$$I_3 = \frac{5V - 0V}{2{,}200} = 2.27mA$$

$$I_{Total} = I_1 + I_2 + I_3 = \sim 75\text{mA}$$

COMPOSITION OF CIRCUITS: LET'S REVIEW

volt·age [**vohl**-tij] | measured in *joules/coulomb* or *volts (V)*

cur·rent [**kur**-*uh*nt] | measured in *coulombs/sec* or *amps (I)*

re·sist·ance [ri-**zis**-t*uhns*] | measured in *ohms (Ω)*

Simplified from: Scherz & Monk, Practical Electronics for Inventors, 3rd Edition]

COMPOSITION OF CIRCUITS: LET'S REVIEW

volt·age [**vohl**-tij] | measured in *joules/coulomb* or *volts (V)*

Voltage pushes electrons in a circuit using an electromotive force (EMF).

cur·rent [**kur**-*uh*nt] | measured in *coulombs/sec* or *amps (I)*

Electric current is the flow of electrons through a wire/conductor. Current always flows from highest potential (voltage) to lowest.

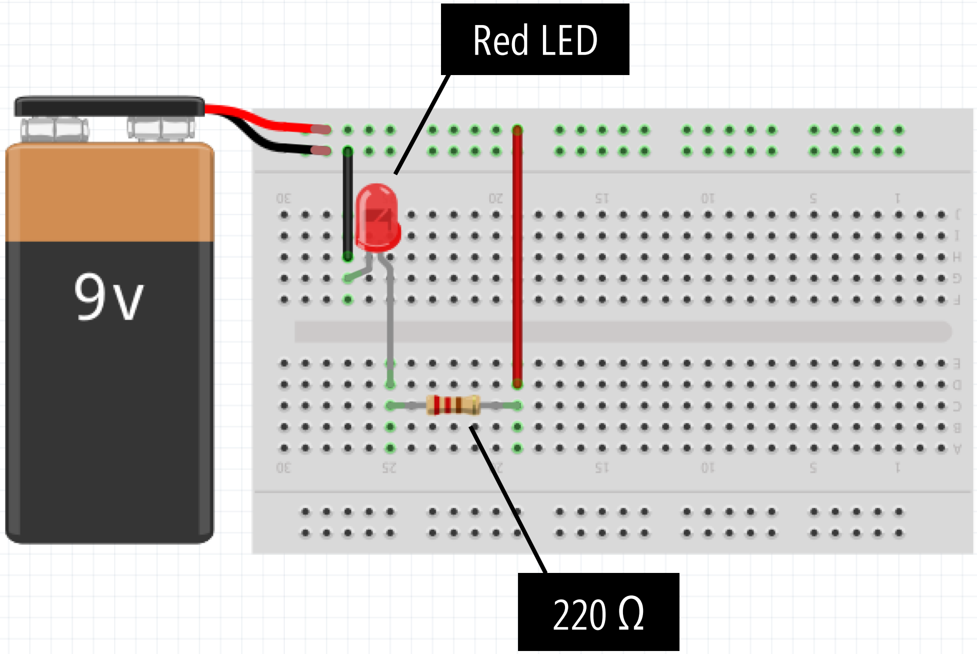
re·sist·ance [ri-**zis**-t*uhns*] | measured in *ohms (Ω)*

A material's tendency to resist the flow of charge (current).

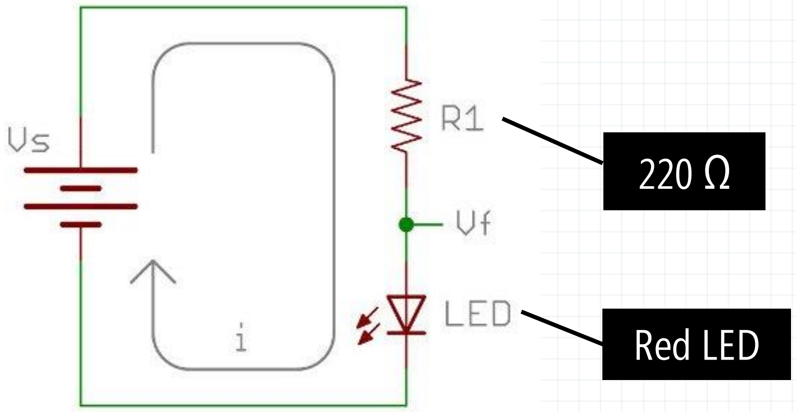
Simplified from: Scherz & Monk, Practical Electronics for Inventors, 3rd Edition]

ACTIVITY

BUILD YOUR FIRST CIRCUIT: RESISTOR + LED



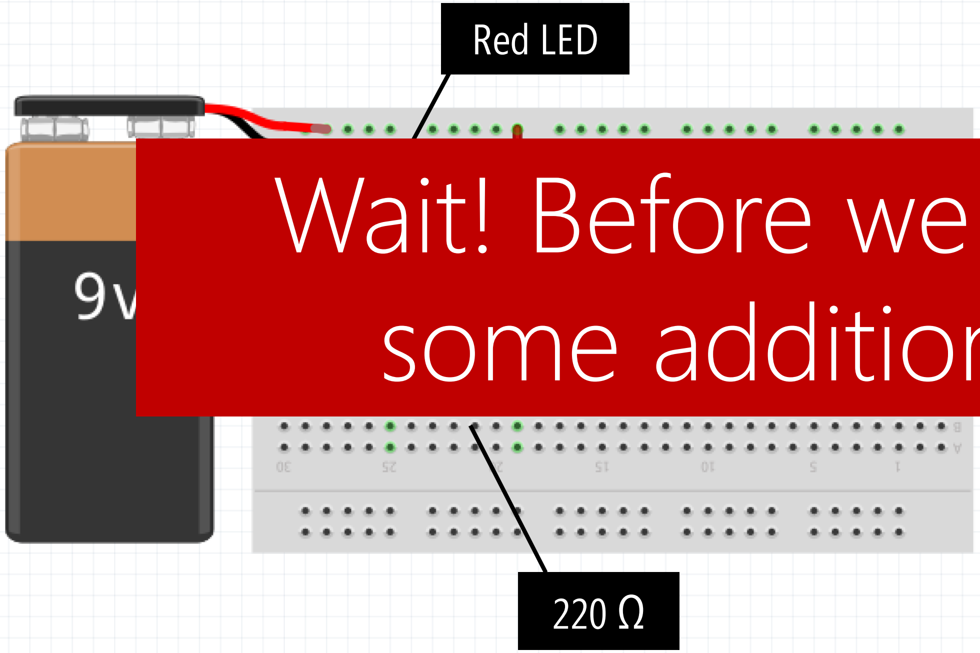
BREADBOARD DIAGRAM



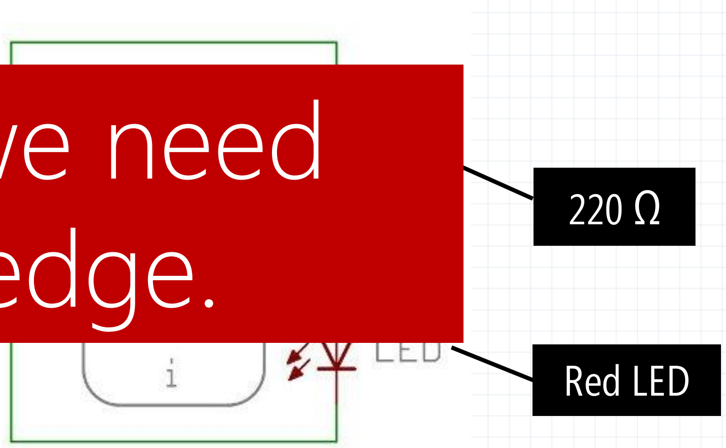
SCHEMATIC VIEW

ACTIVITY

BUILD YOUR FIRST CIRCUIT: RESISTOR + LED



BREADBOARD DIAGRAM



SCHEMATIC VIEW

Wait! Before we do this, we need some additional knowledge.

DANGEROUS CURRENT LEVELS

DC Current	Probable effect on human body
1 - 5 mA	Tingling sensation
5 - 10 mA	Pain
10 - 20 mA	Involuntary muscle contractions
20 - 100 mA	Paralysis, heart stoppage

Current can be **dangerous—high amperage** is what can kill you or cause tissue damage.

When you come into contact with a live wire or energized object, the amount of current that passes through your body to ground depends on the voltage level and your internal resistance.

The NIOSH states "Under dry conditions, the **resistance offered by the human body may be as high as 100,000 Ohms**. Wet or broken skin may drop the body's resistance to 1,000 Ohms," adding that "high-voltage electrical energy quickly breaks down human skin, reducing the human body's resistance to 500 Ohms."

Source: Scherz & Monk, Practical Electronics for Inventors, 3rd Edition; https://www.sparkfun.com/news/1385; http://en.wikipedia.org/wiki/Electric_shock

CURRENTS IN PERSPECTIVE

It's a good idea to have some idea of typical current draws when working with electronics.

Low-Power Microchip
A few µA or pA

Typical LED
Draws 20mA

SmartPhone
Draws ~200mA loading a webpage

100W lightbulb
Draws about 1A

Laptop
Draws ~2-3A

Toaster
Draws about 7-10A

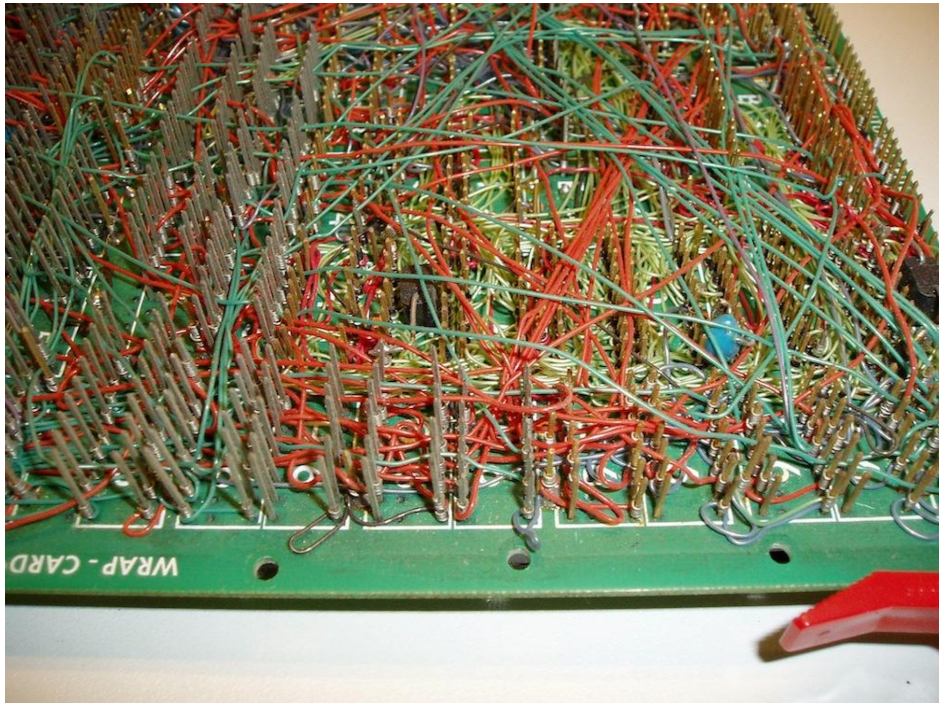
Microwave
Draws 8-13A

Lightening Strike
Around 1000A

Source: Scherz & Monk, Practical Electronics for Inventors, 3rd Edition]

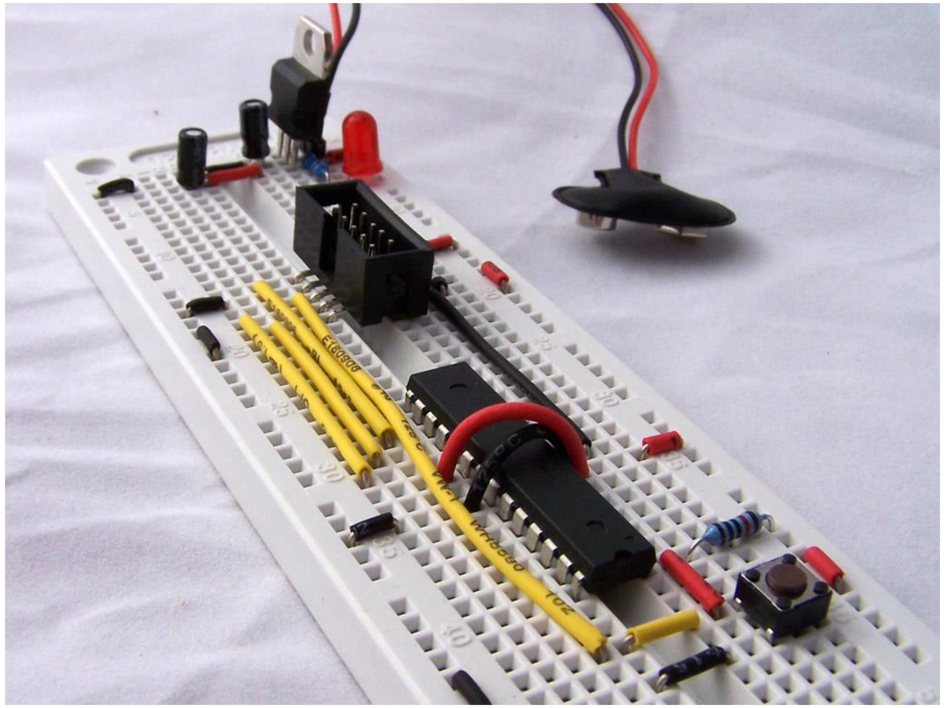
WHAT IS A BREADBOARD?

Breadboards are quick way of wiring and prototyping circuits



WIRE WRAPPING CIRCA ~1960

Wire wrapping involved wrapping wires around conductive posts attached to perfboards



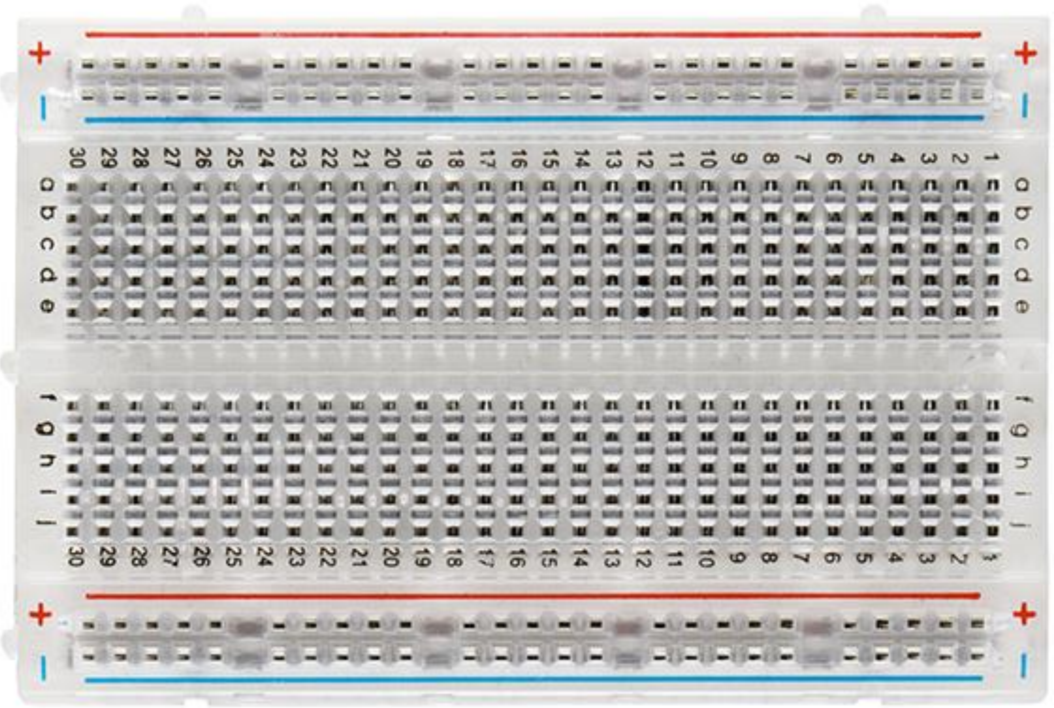
BREADBOARDING

Breadboards simplify this by having some wiring "built-in," which are accessed via holes.

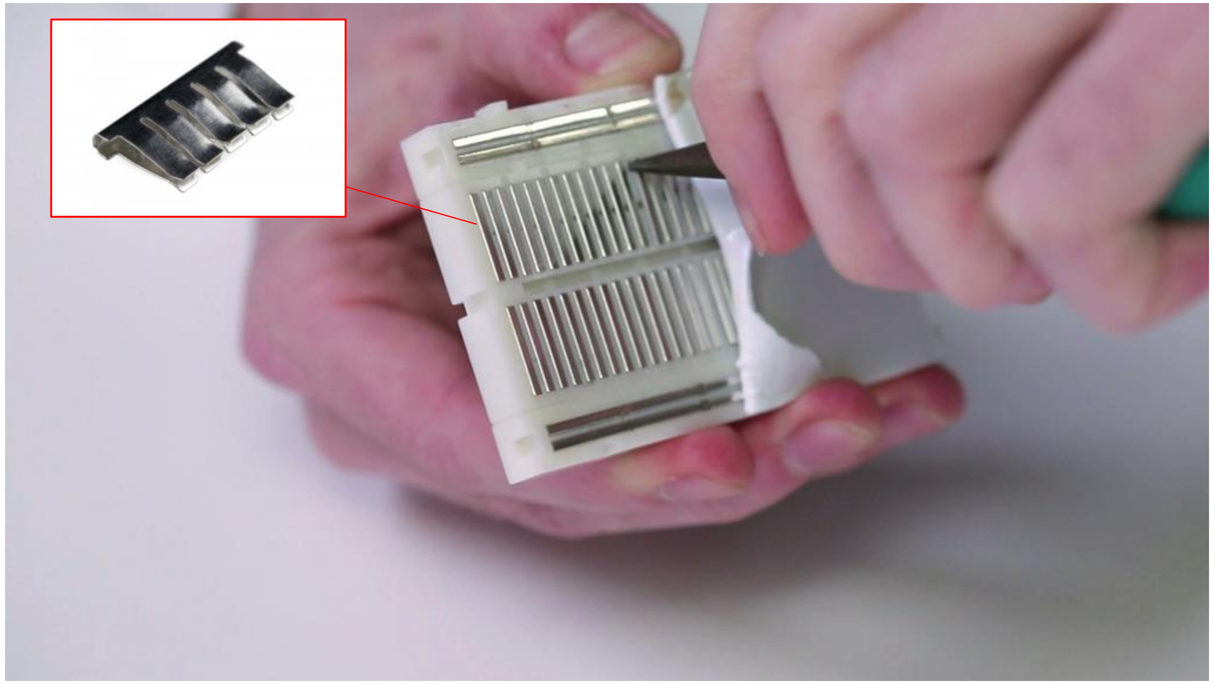
Source: https://learn.sparkfun.com/tutorials/how-to-use-a-breadboard

HOW DO BREADBOARDS WORK?

Breadboards are simply pre-wired boards. They are always a bit confusing at first. It will just take a bit of experience to get comfortable!



Top of Breadboard
Viewed from the top



Inside Breadboard
Viewed from the bottom

HOW DO BREADBOARDS WORK?

Wire 2: Similarly, all of these holes are hooked together (forming a new wire)

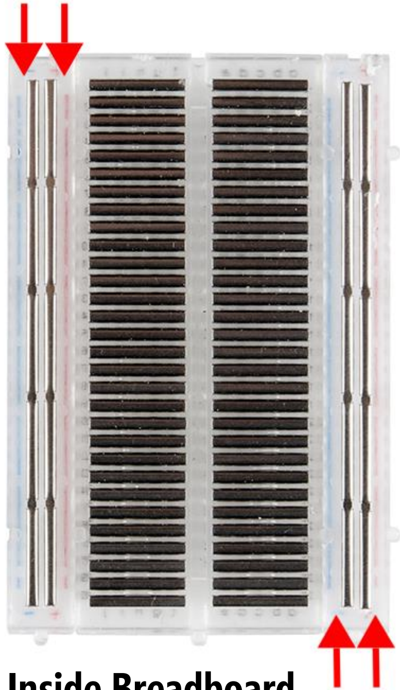
Wire 1: All of these holes are hooked together (to the same wire)

ROW SET 1
Each row wired together

COLUMN SET 1
Each column wired together

COLUMN SET 2
Each column wired together

ROW SET 2
Each row wired together



Inside Breadboard
Viewed from the bottom

Importantly, wires do not cross this channel. So, the other side of a breadboard provides additional wiring

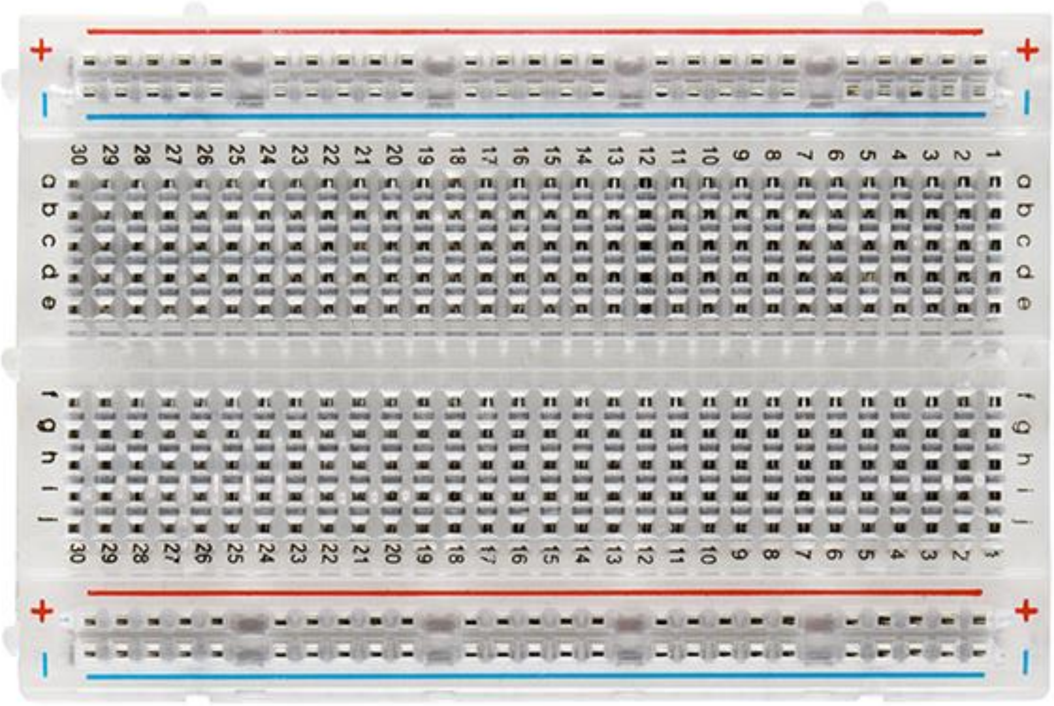
BREADBOARD TIP 1

ROW SET 1
Each row wired together

COLUMN SET 1
Each column wired together

COLUMN SET 2
Each column wired together

ROW SET 2
Each row wired together



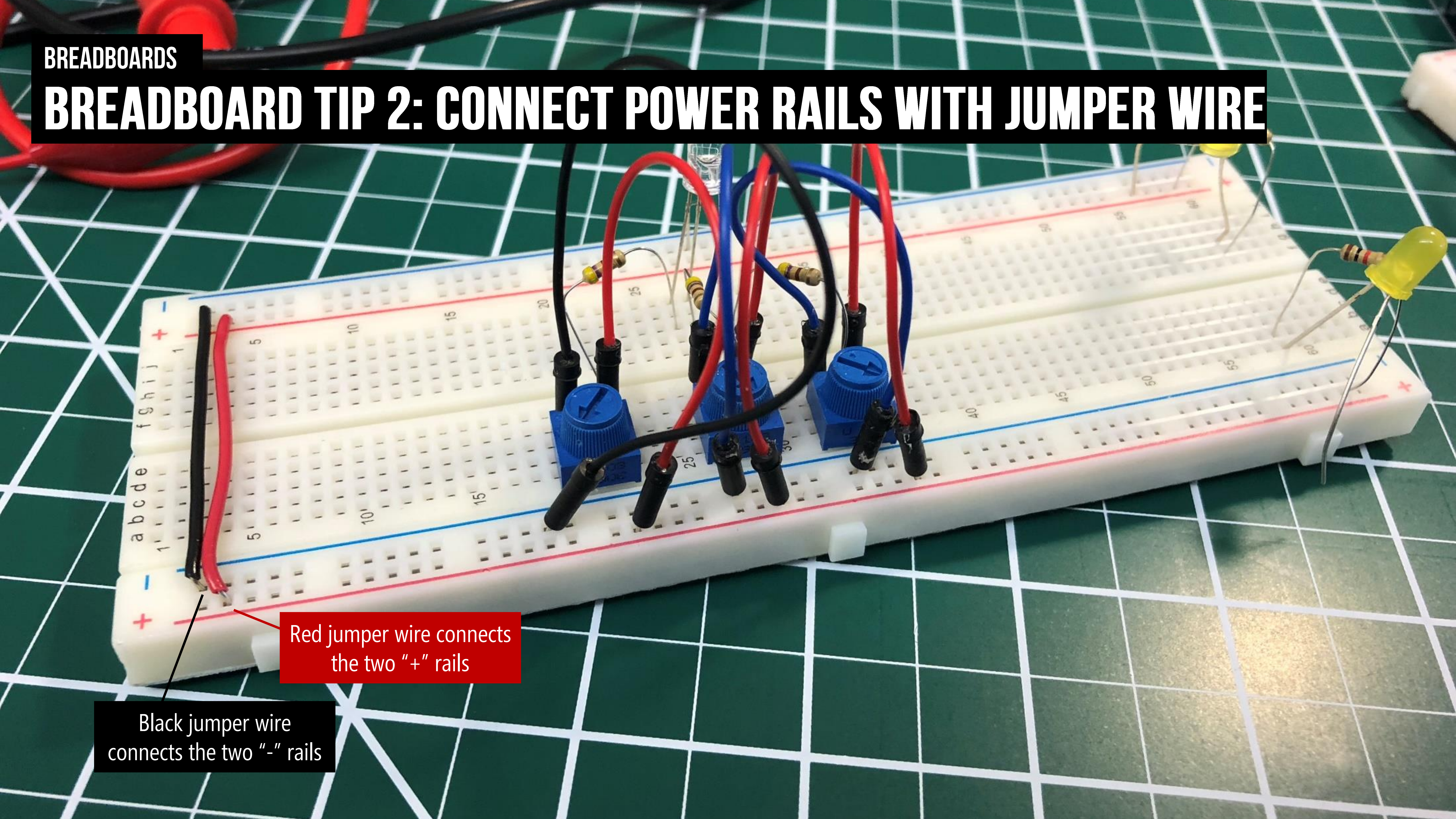
Typically we hooked up **Vs** (our positive voltage source) here

And we hook up **GND** (ground) here.

This wiring configuration just makes things easier.

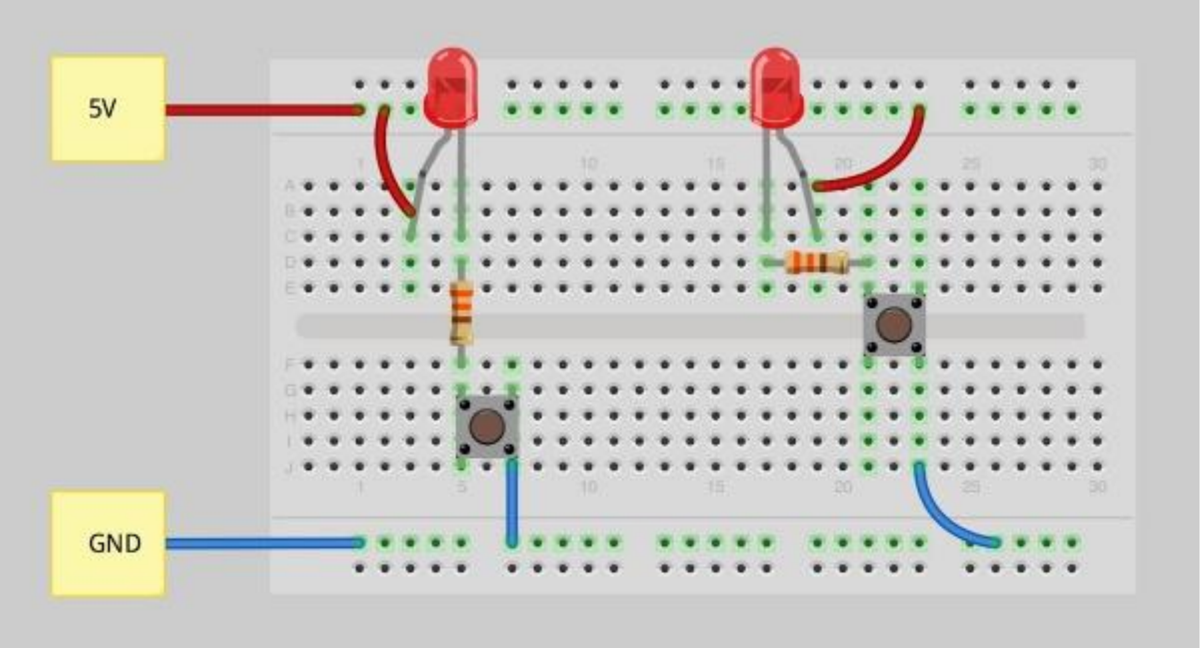
In fact, this part of the breadboard is often called "power rails"

BREADBOARD TIP 2: CONNECT POWER RAILS WITH JUMPER WIRE



BREADBOARD TIP 3: DEFENSIVE BREADBOARDING

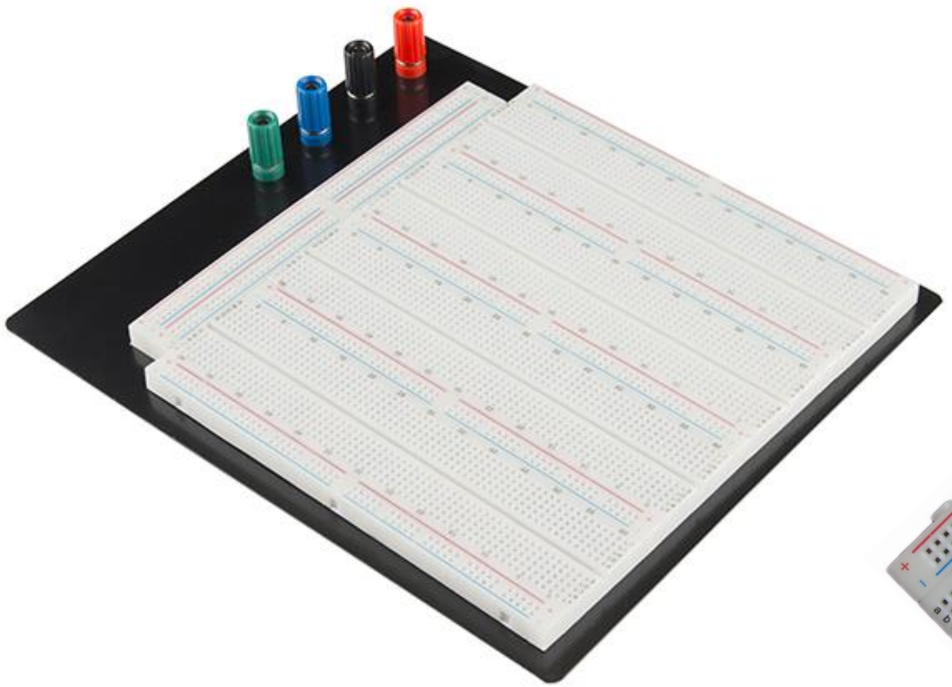
Some choose to only connect power on one side of the breadboard and ground on the other to reduce the chance of accidentally plugging a wire into the wrong socket and shorting out a circuit.

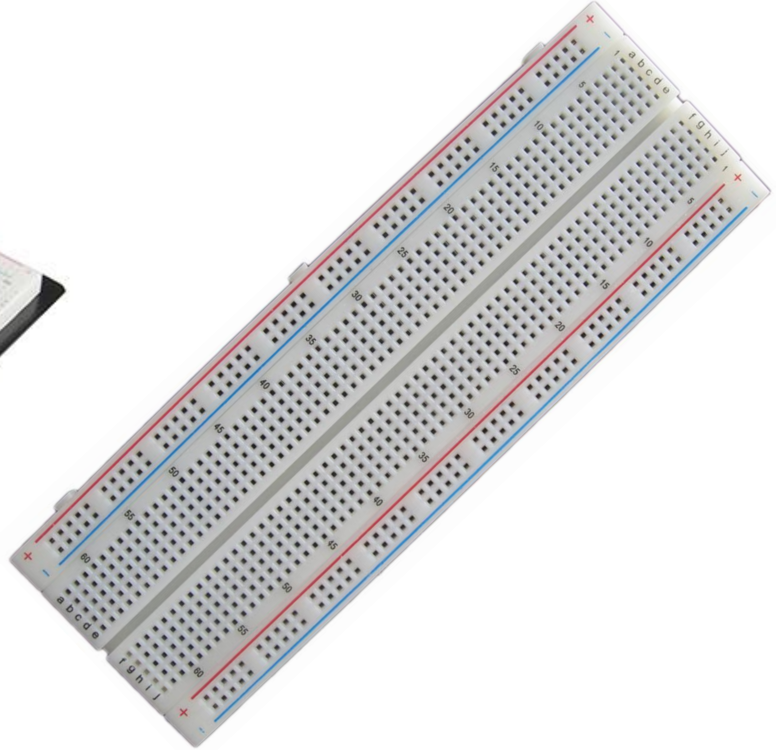


Notice how the 5V and GND rails are only connected on opposite sides of the breadboard. This is to limit stupid mistakes!

Source: https://learn.adafruit.com/assets/17394, https://learn.sparkfun.com/tutorials/how-to-use-a-breadboard

LOTS OF DIFFERENT BREADBOARD SIZES





Which breadboards do you have in your Arduino kits?

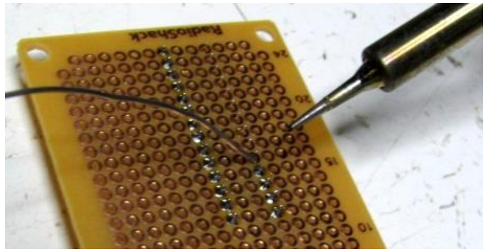
BREADBOARDS ARE LIKE LEGOS!

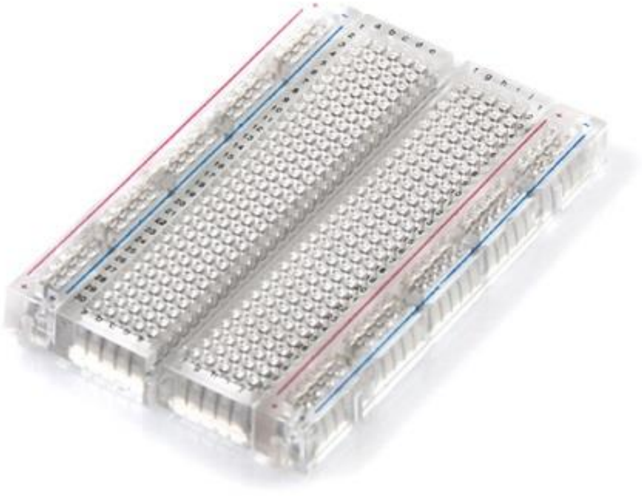
Many breadboards have little nubbins and slots on the sides, and some even have them on the tops and bottoms. These allow you to connect multiple breadboards together to form the ultimate prototyping surface.

[source: sparkfun.com]

BREADBOARDS VS. PERFBOARDS

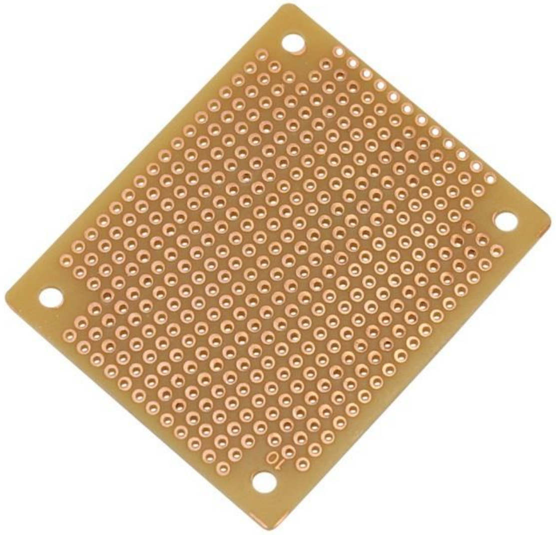
Typically, you start prototyping on a breadboard but then switch over to something like a perfboard once your design is starting to solidify or you want something more permanent. Perfboards require soldering.





Breadboard

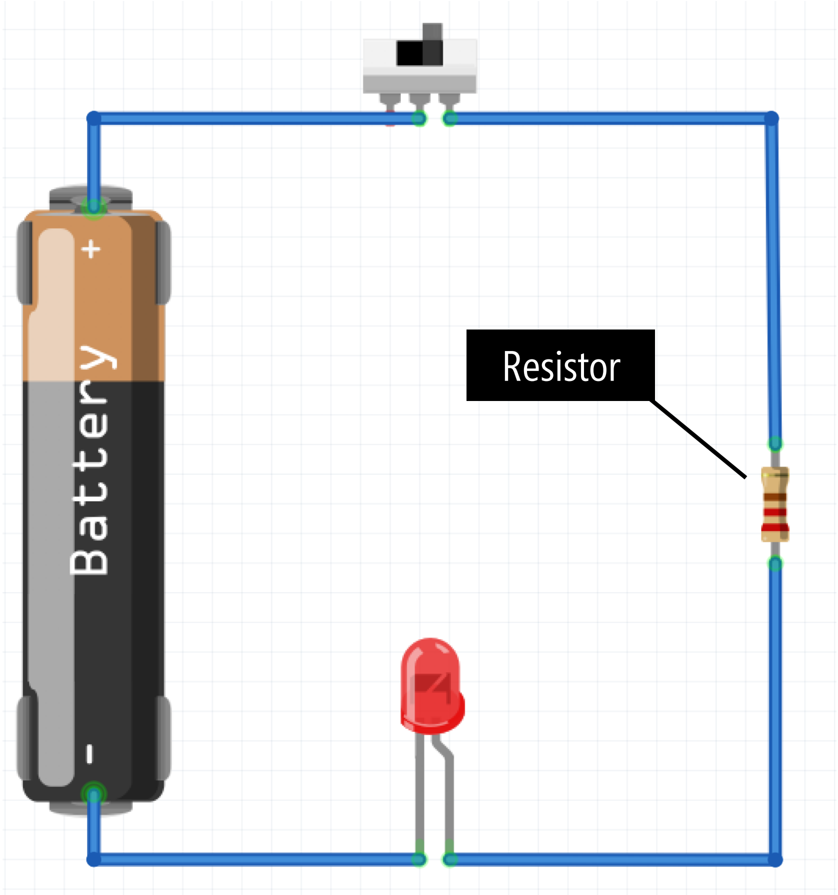
!=

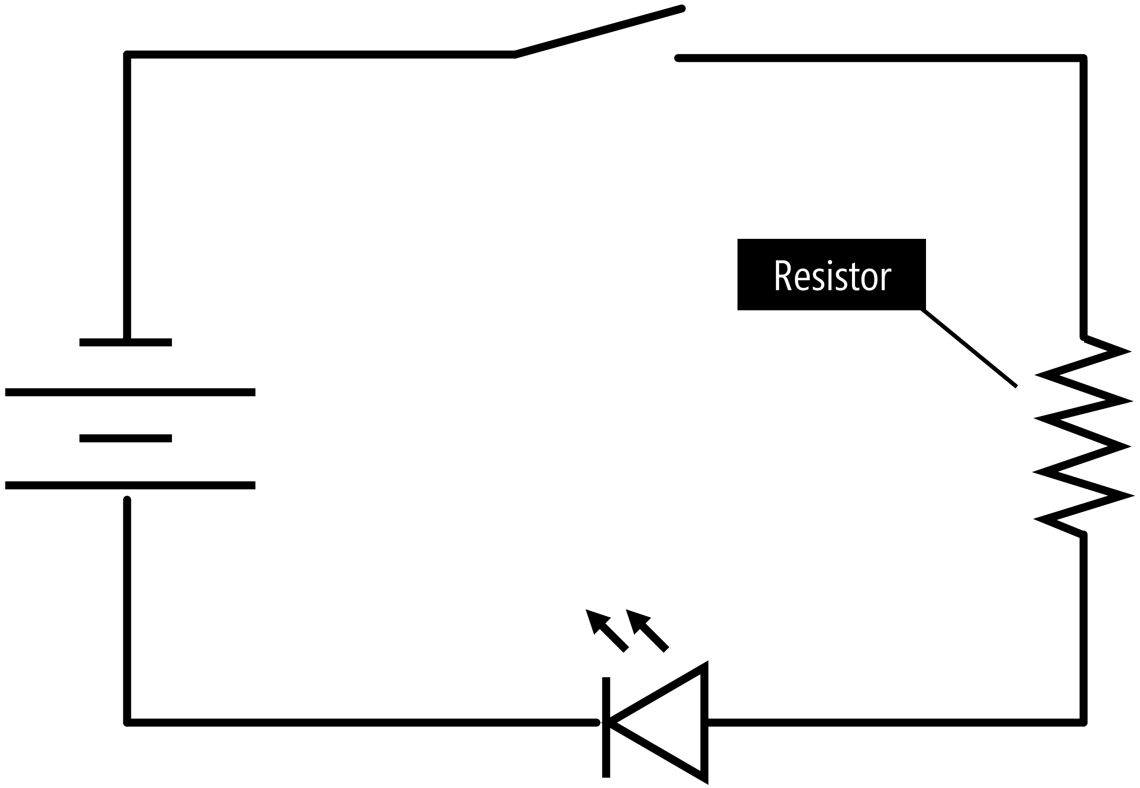


Perfboard

[source: https://learn.adafruit.com/collins-lab-breadboards-and-perfboards/transcript,]

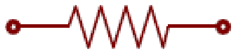
WHAT IS A RESISTOR?





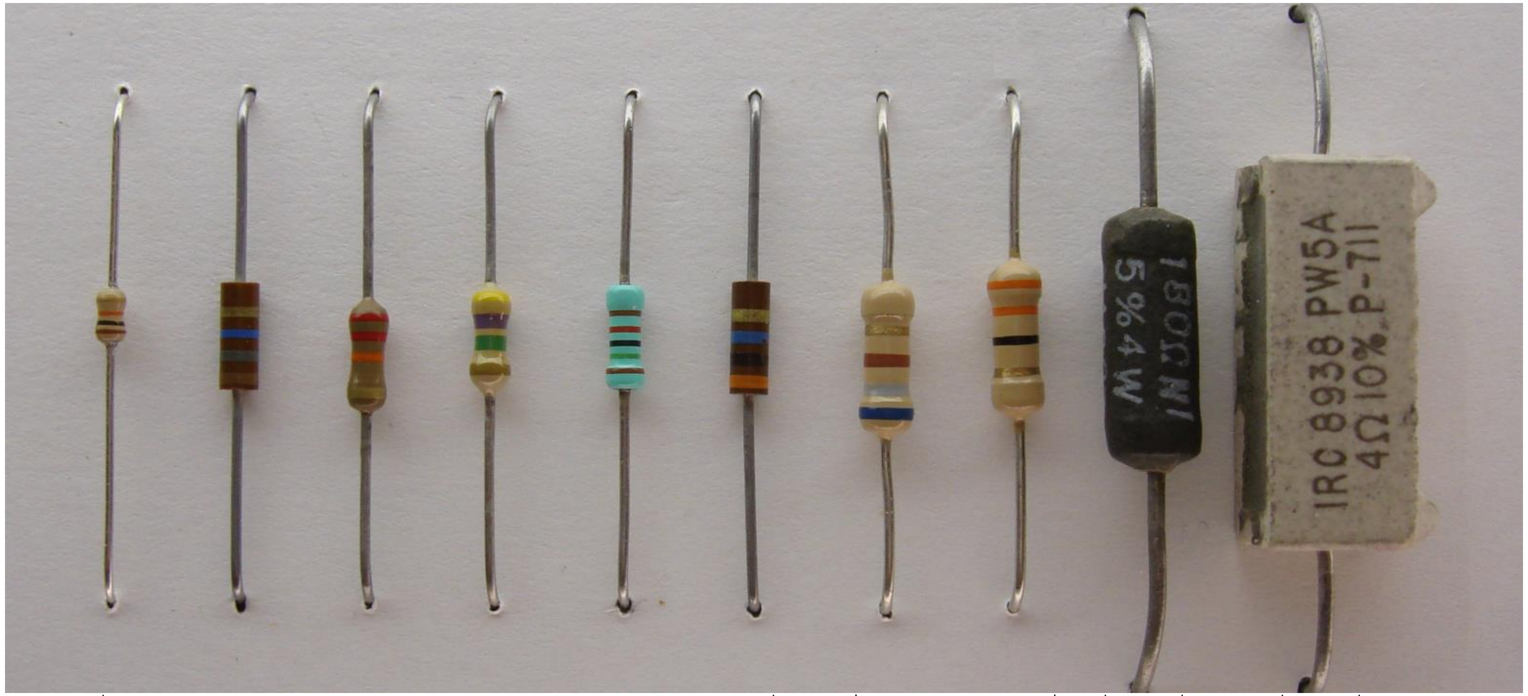
WHAT IS A RESISTOR?

American-Style Symbol



International-Style Symbol

Resistors limit the flow of electrons through a circuit by converting electrical energy to thermal energy (heat).



¼ W resistors ½ W resistors 4 W 5 W

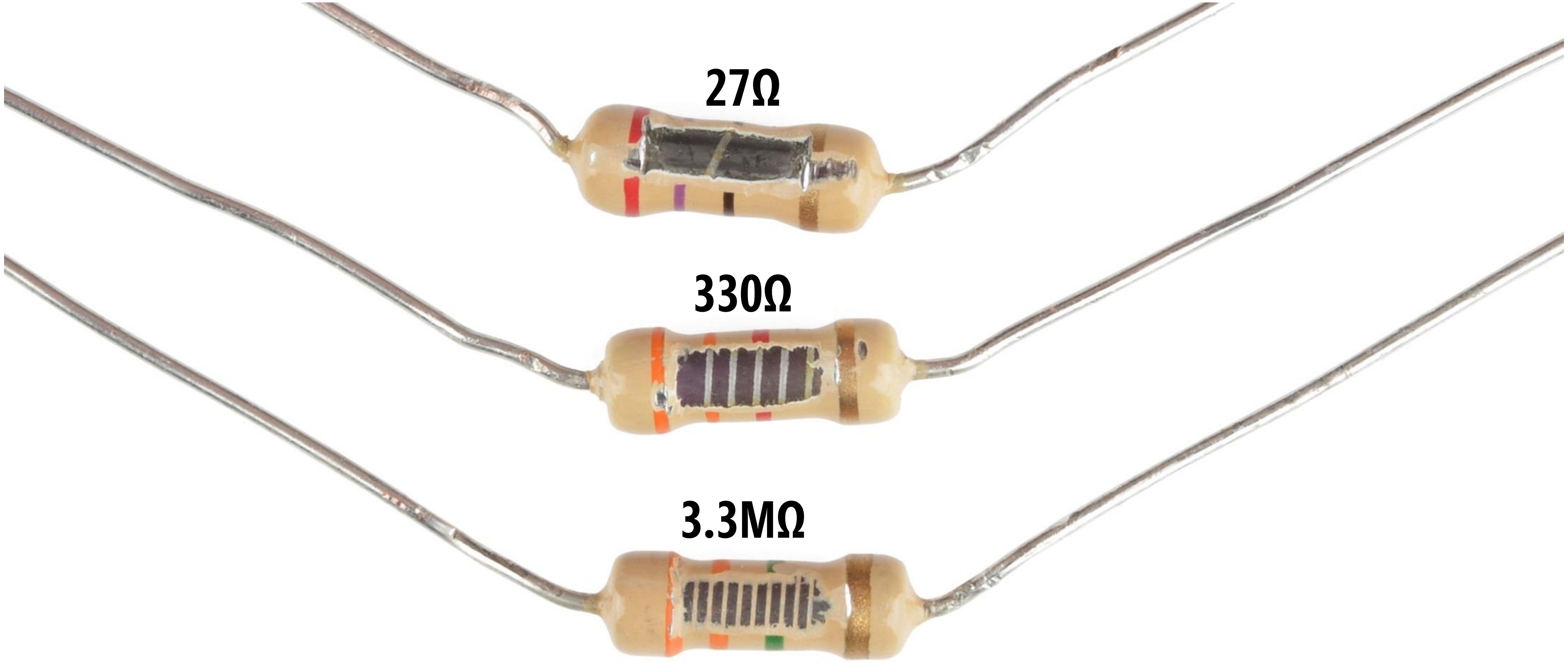
Resistors have no polarity so you can put them into a circuit in either orientation.

Resistors are characterized by their **resistance value (in Ohms or Ω)** and their **maximum power capacity (in Watts),** which is the maximum rate at which they can convert electrical energy to thermal energy.

Source: https://learn.sparkfun.com/tutorials/resistors

RESISTOR COMPOSITION

Resistors are composed of a thin film of conductive material wrapped around an insulating material. The more wraps, the higher resistance.

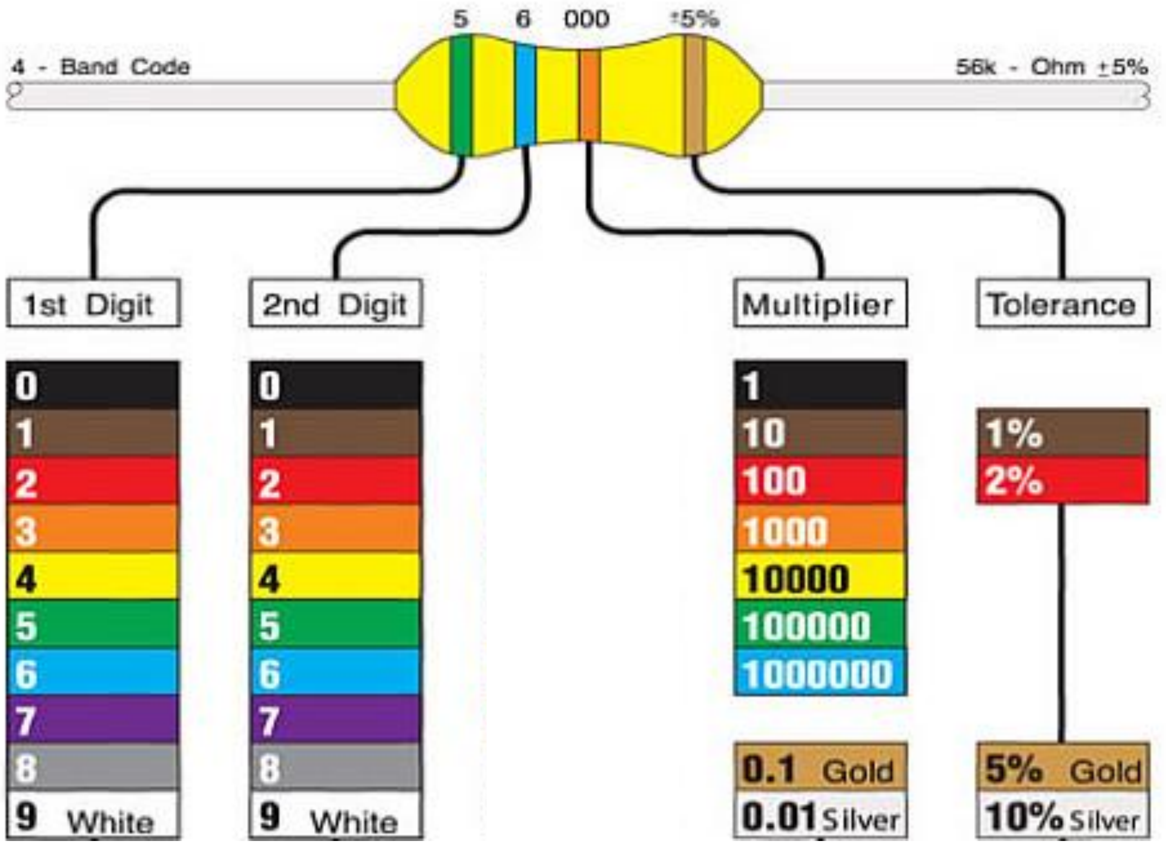


Source: https://learn.sparkfun.com/tutorials/resistors

READING A RESISTOR'S VALUE

Resistors have color-coded stripes indicating their resistance value

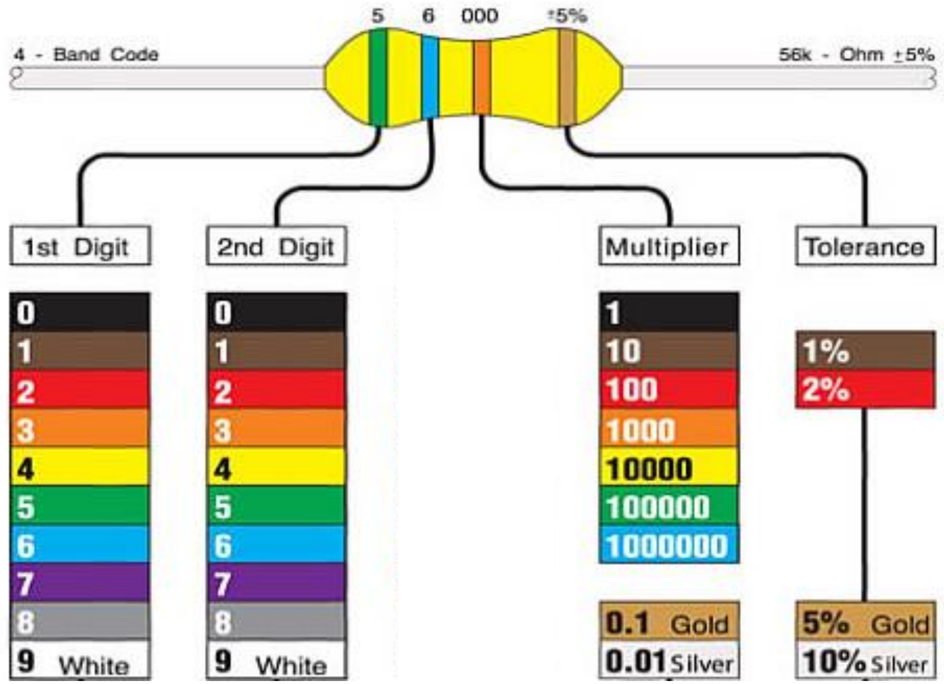
The tolerance stripe is always gold (5%) or silver (10%), which enables you to orient the resistor to read left-to-right



Source: https://www.electro-tech-online.com/tools/images/cheat-sheets-resistor.gif

EXERCISE: READING A RESISTOR'S VALUE

Resistors have color-coded stripes indicating their resistance value



What is the value of this resistor?

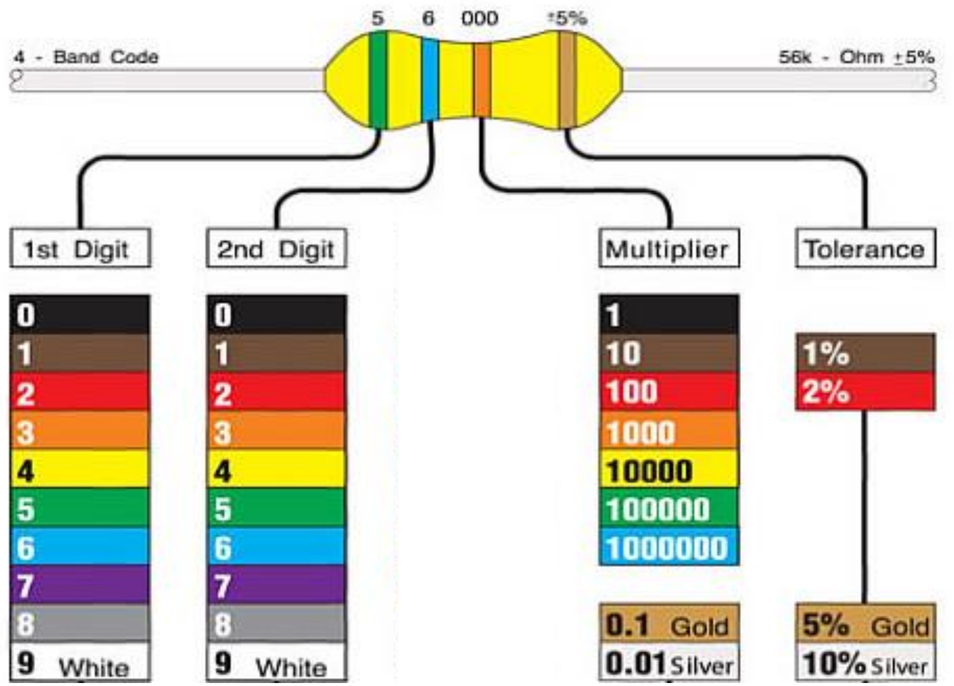
Red, red, brown, gold

What is the value of this resistor?

Brown, black, orange, gold

Source: https://www.electro-tech-online.com/tools/images/cheat-sheets-resistor.gif

READING A RESISTOR'S VALUE



What is the value of this resistor? 220Ω

Red, red, brown, gold = 2, 2, 10, 5% = 22 * 10 = 220Ω

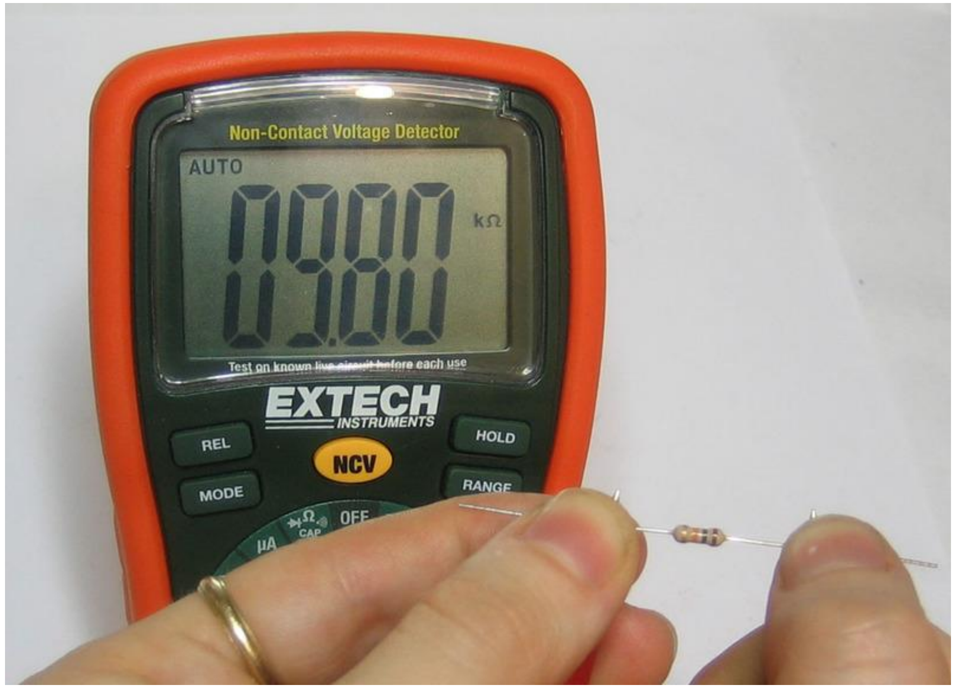
What is the value of this resistor? 10,000Ω or 10KΩ

Brown, black, orange, gold = 1, 0, 1000, 5% = 10 * 1000 = 10KΩ

Source: https://www.electro-tech-online.com/tools/images/cheat-sheets-resistor.gif

READING A RESISTOR: TWO STRATEGIES

Keep Your Resistors Organized
I typically buy the SparkFun Resistor Kit, which comes organized by resistor value.

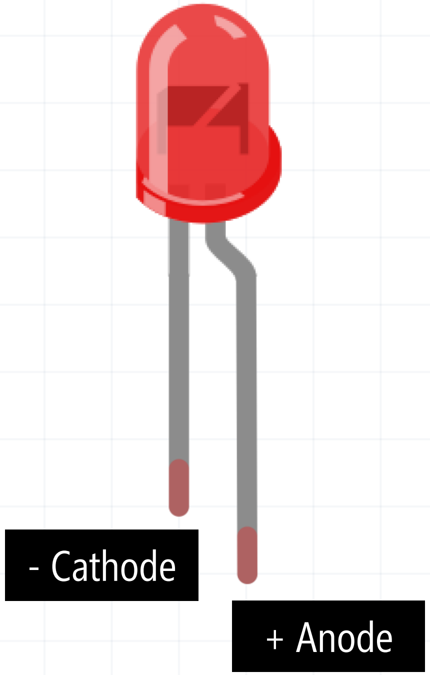


Use a Multimeter
Make sure that the resistor is not connected to anything else and switch the multimeter to its resistance measurement setting

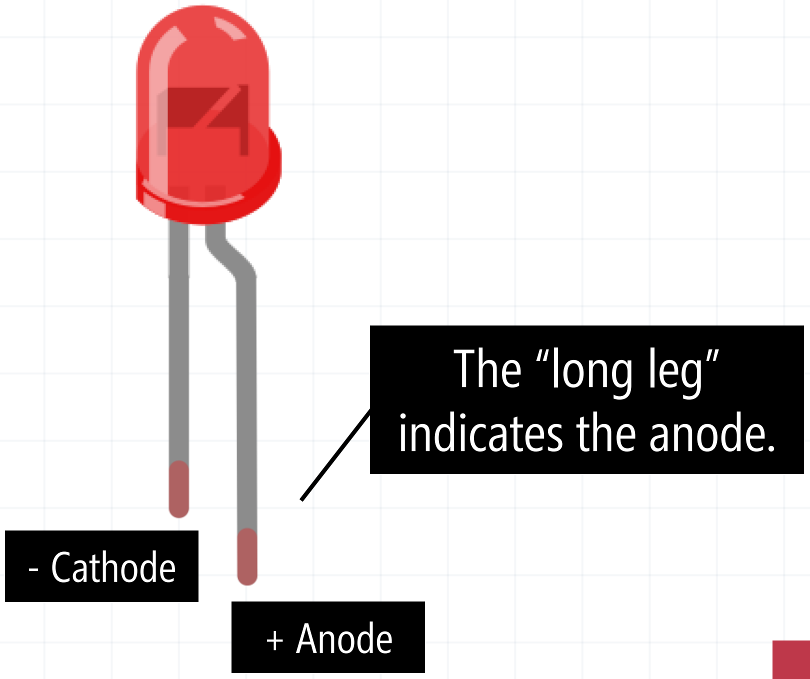
USING LEDS

WHAT IS A LIGHT-EMITTING DIODE (LED)?

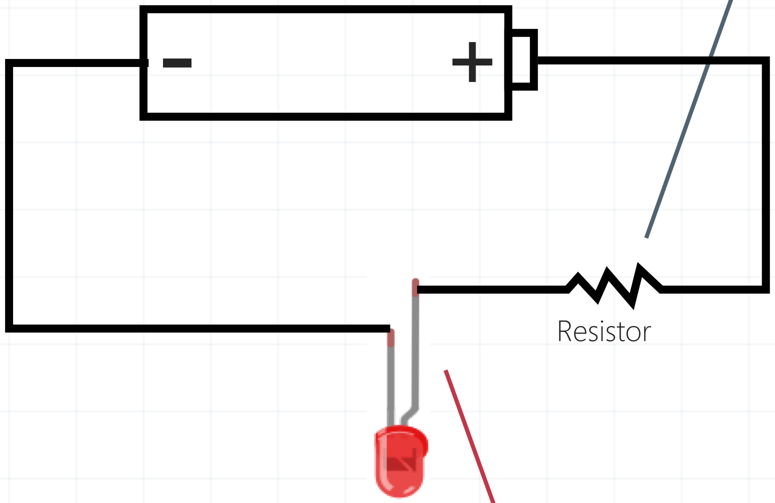
LEDs emit light when certain voltage and current requirements are met.



LIGHT-EMITTING DIODES (LEDS)



LEDs require **current limiting resistors**. Do not hook up an LED directly to a power source without a resistor or the LED could burn out.



Unlike resistors, LEDs have **polarity**. They only allow current to flow in one direction. The long leg (the anode) must be connected towards positive supply voltage.

DIODES: FORWARD VOLTAGE

A diode (including an LED) won't allow current through unless a **forward voltage** condition is met. The LED datasheet will tell you what this is (*e.g.*, 1.8-2.5V). Let's use another water analogy.

Source:: http://husk.eecs.berkeley.edu/courses/cs294-84-fall14/images/a/a3/Slides-02-electronics101.pdf

DIODES: FORWARD VOLTAGE

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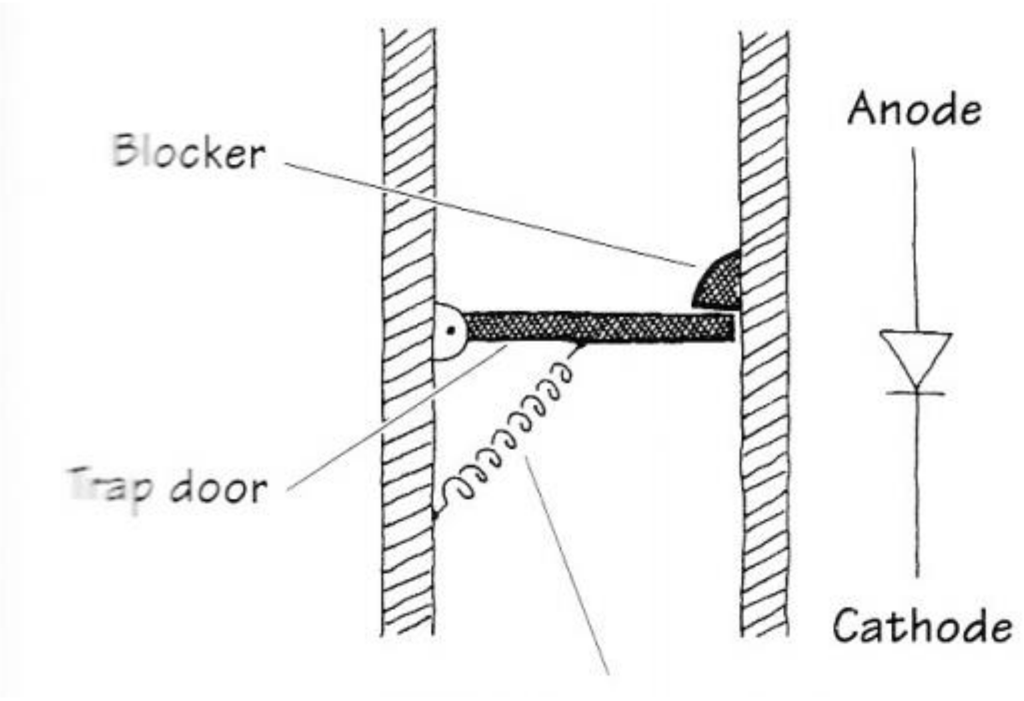
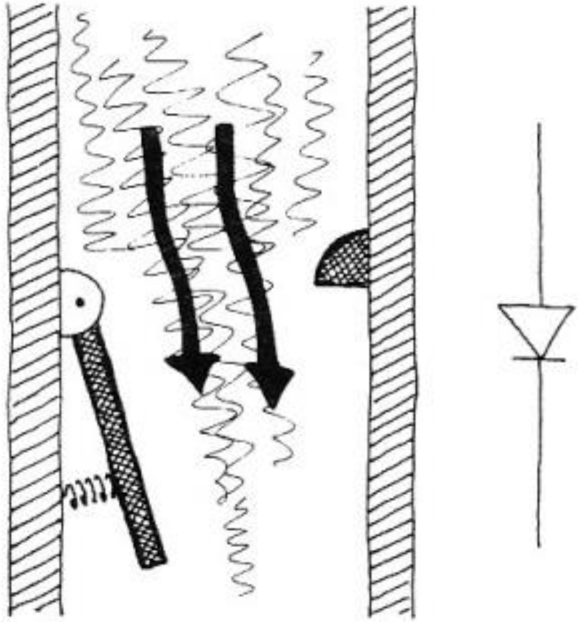


Imagine this trap door won’t open unless a certain water pressure threshold is met (this is the forward voltage).

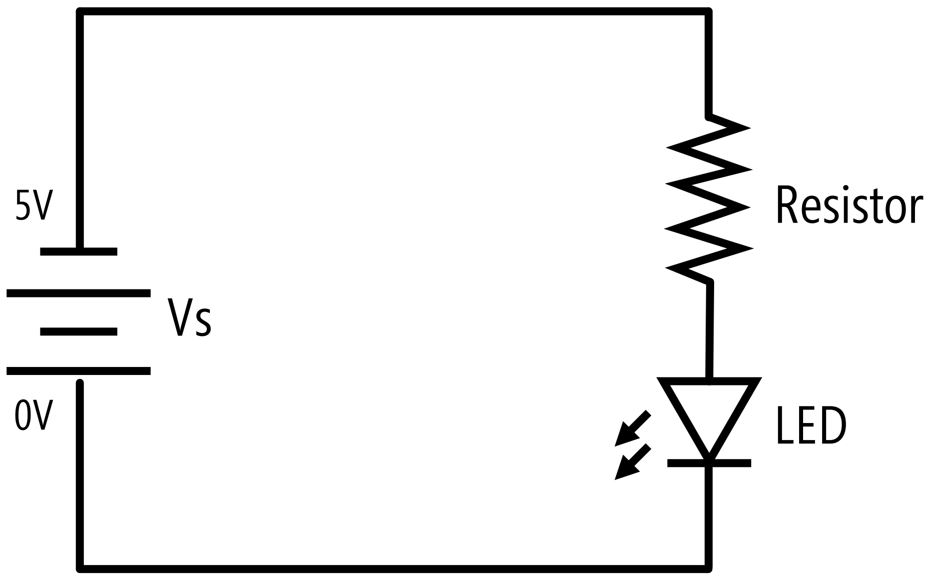


Once the threshold is met, the trap door opens and water (current) passes through.

Source:: http://husk.eecs.berkeley.edu/courses/cs294-84-fall14/images/a/a3/Slides-02-electronics101.pdf

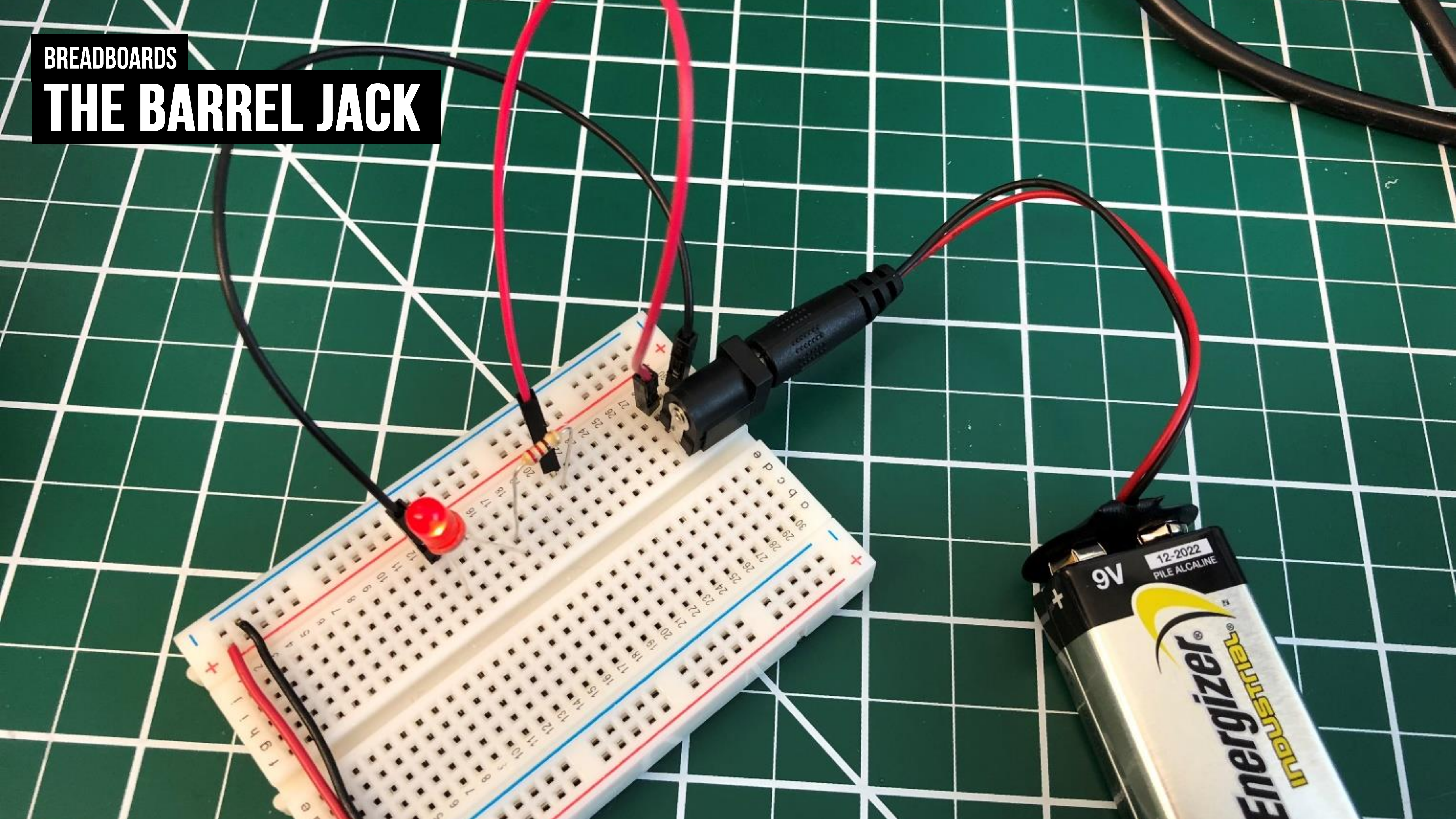
EXERCISE: LET'S HOOKUP OUR FIRST CIRCUIT!

Let's make this on a breadboard!

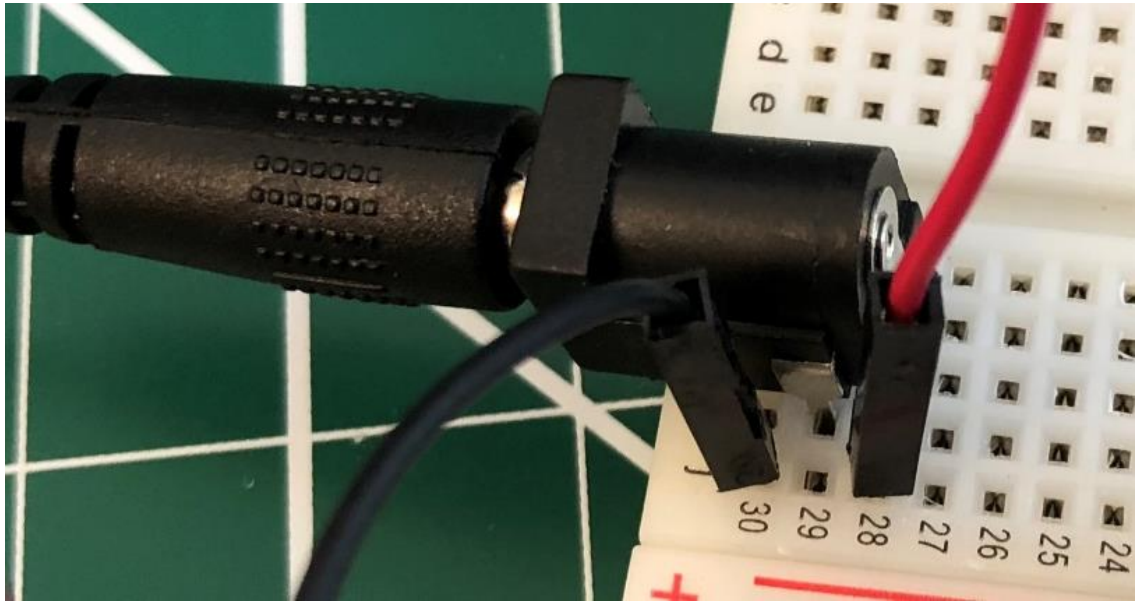


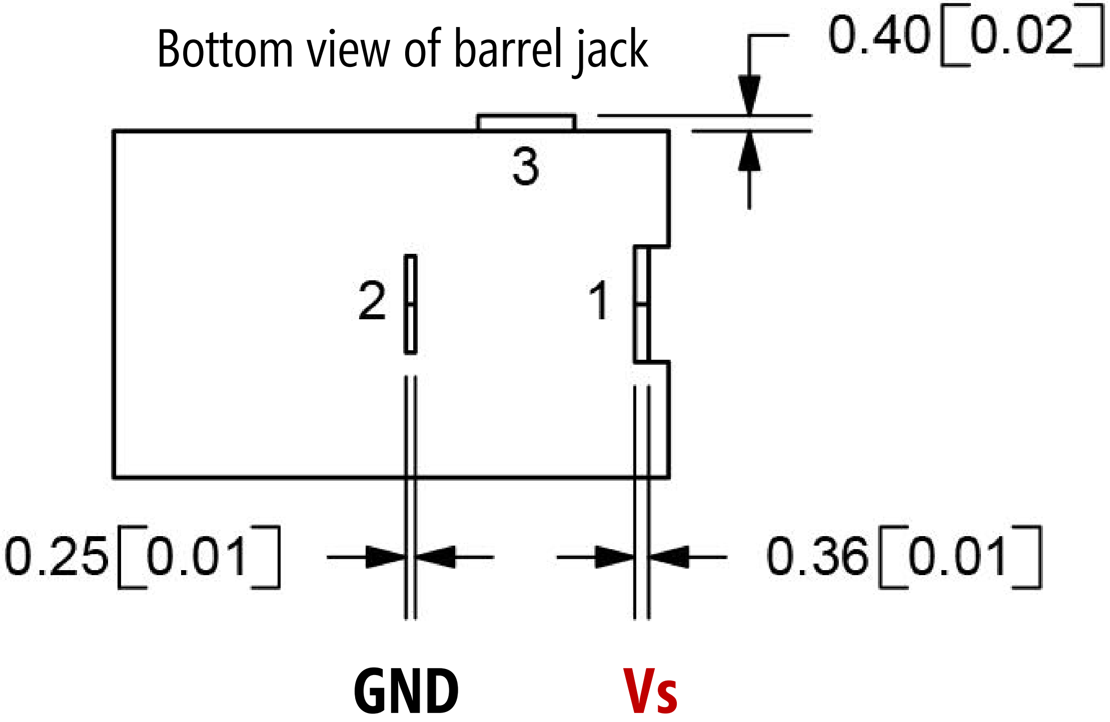
BREADBOARDS

THE BARREL JACK



THE BARREL JACK

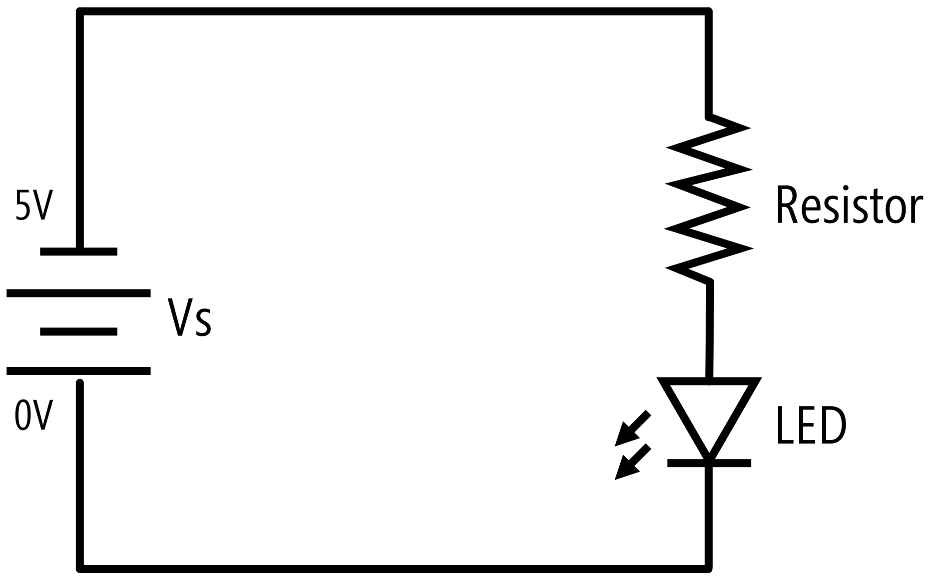




https://cdn.solarbotics.com/products/datasheets/pj-002a.pdf

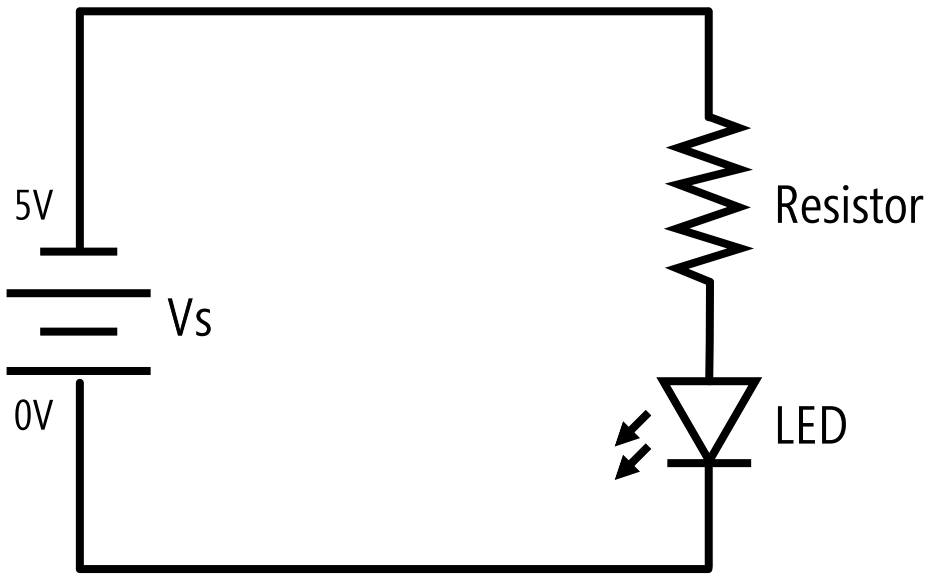
EXERCISE: LET'S HOOKUP OUR FIRST CIRCUIT!

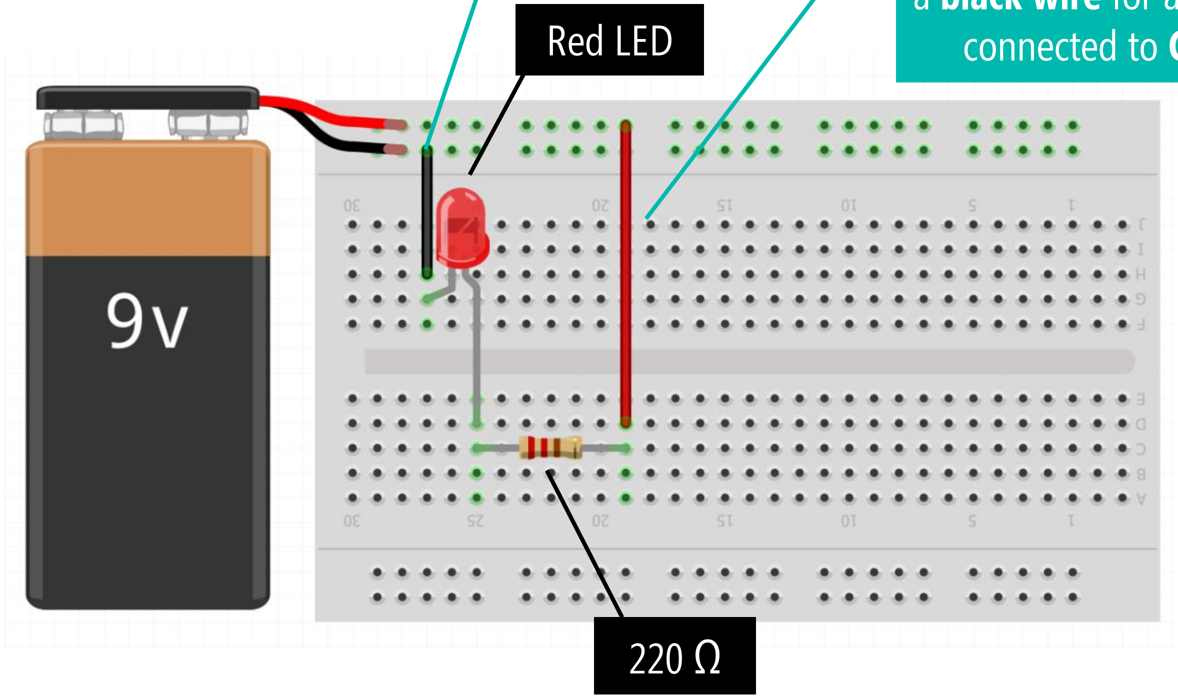
Let's make this on a breadboard!



EXERCISE: ONE POTENTIAL ANSWER

Let's make this on a breadboard!

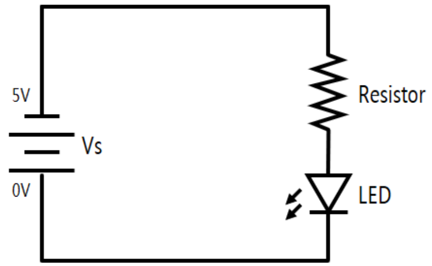




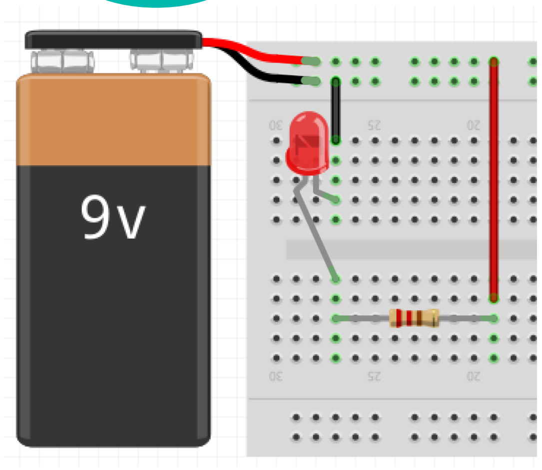
Breadboarding Tip:
Carefully use wire color to indicate function. I like to use a **red wire** for any wire connected to Vs and a **black wire** for any wire connected to **GND**

BREADBOARDS

EXERCISE: CORRECT OR INCORRECT?



Correct or Incorrect?



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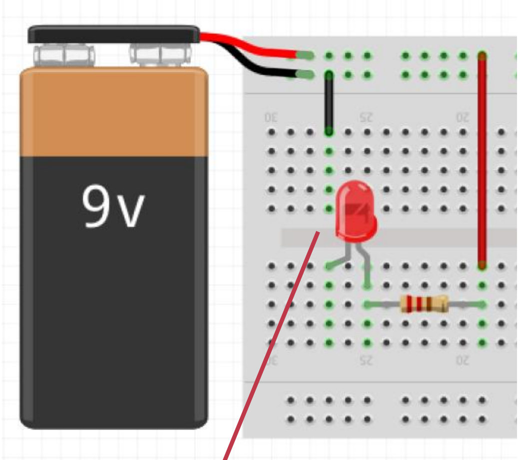

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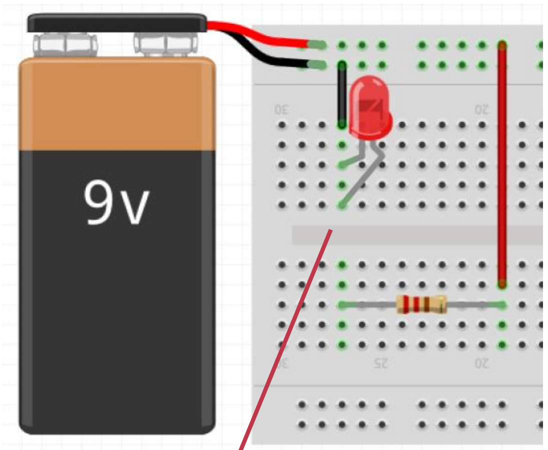
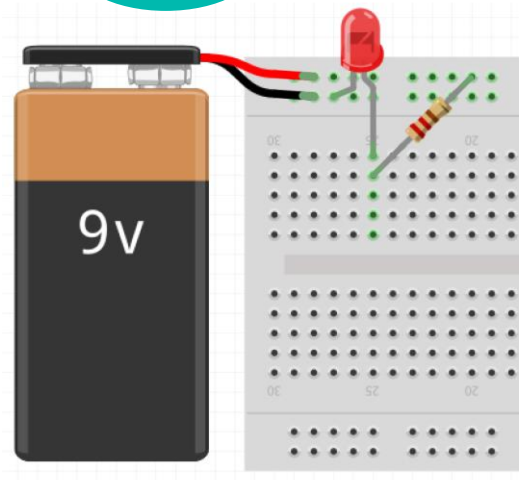


Correct or Incorrect?

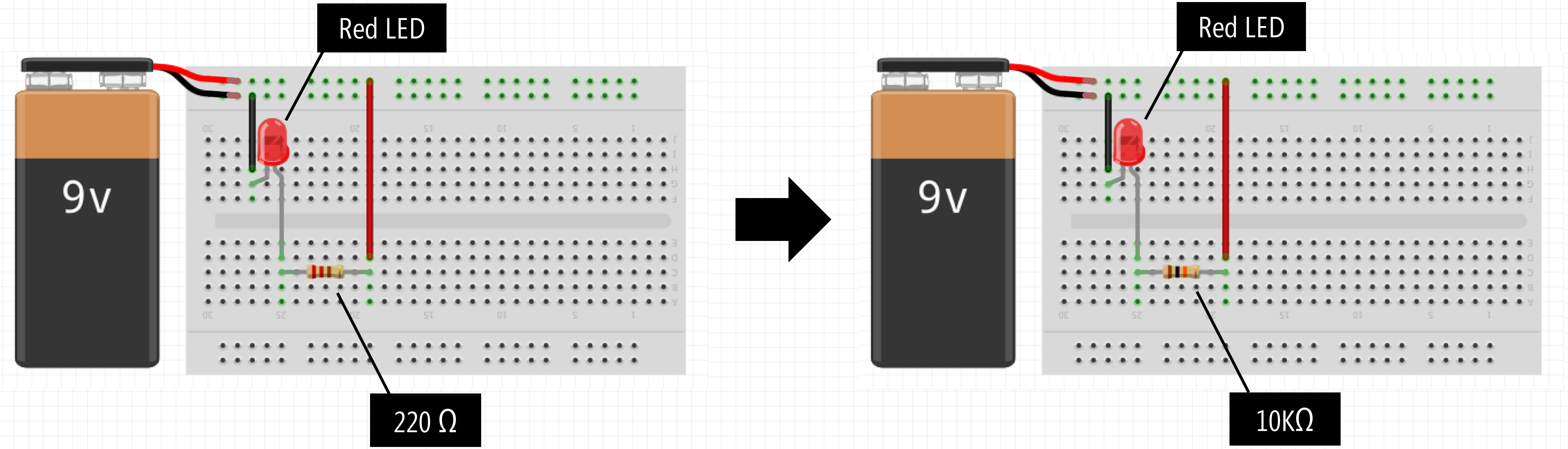


Recall that these **columns are not connected** across this split/gulf. So, the LED is not actually connected to the black wire (GND).

The **LED is connected to itself** as both legs are connected to the same column. The **LED also is not connected to the resistor** as it does not span the gulf.

ACTIVITY

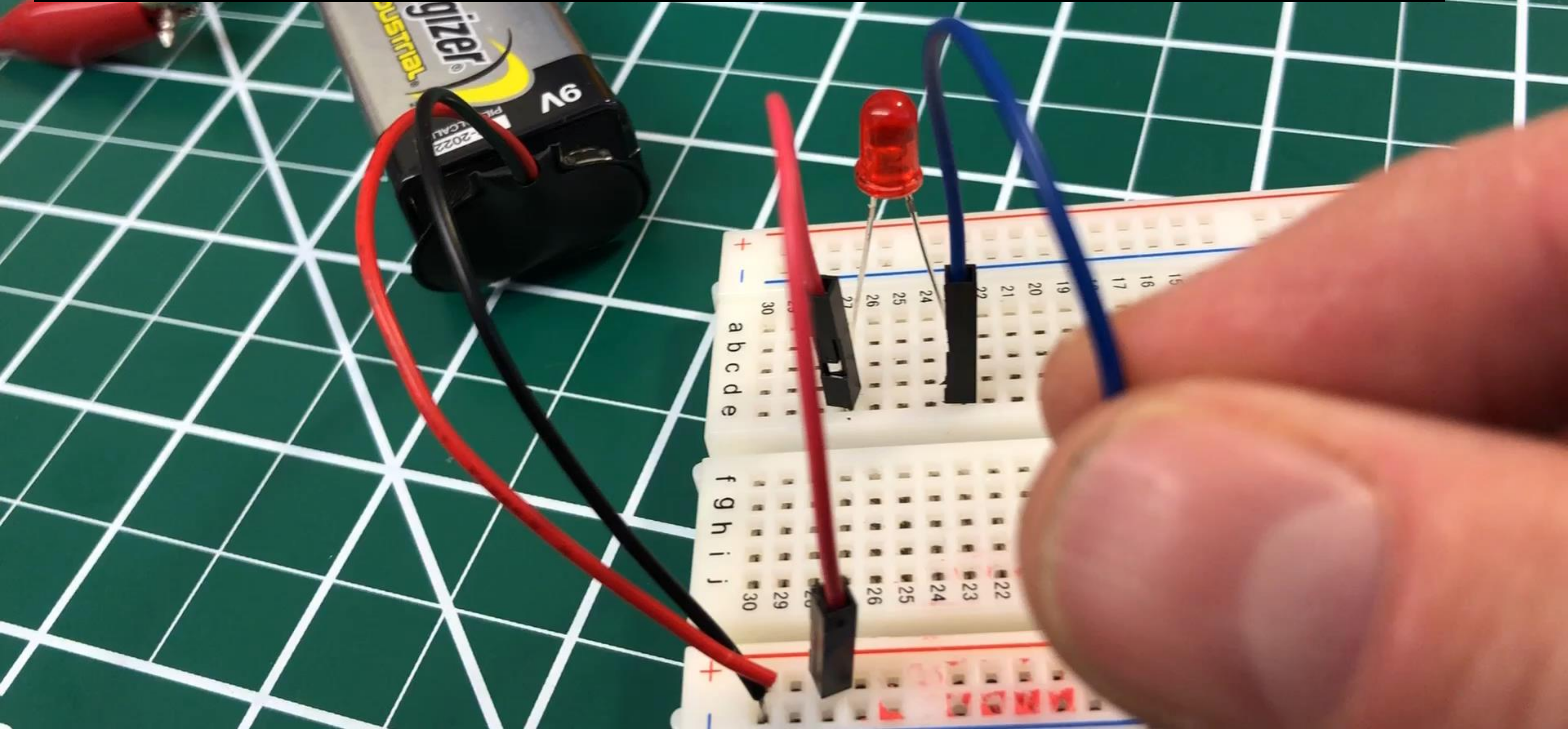
SWAP THE 220 OHM RESISTOR WITH A 10K RESISTOR

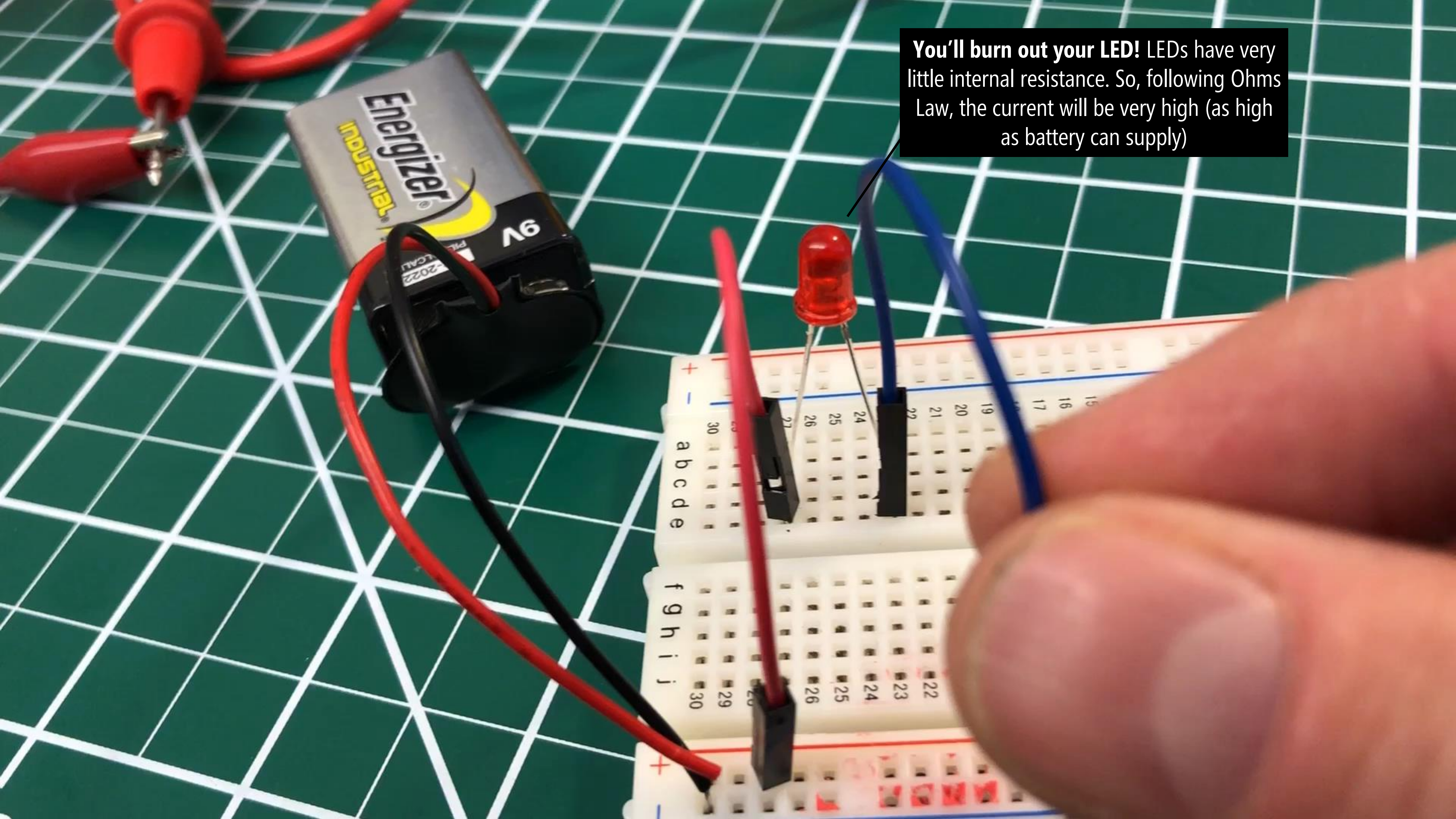


What happens to the LED? Does it get brighter or dimmer? Why?

USING LEDS

WHAT HAPPENS IF YOU DON’T USE A CURRENT LIMITING RESISTOR?



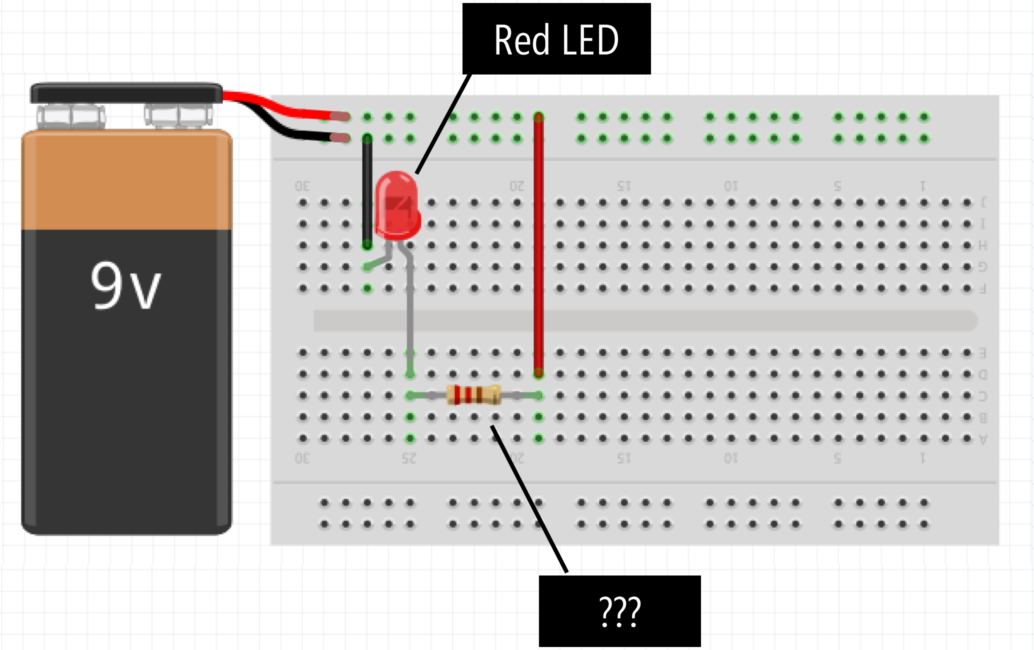

You'll burn out your LED! LEDs have very little internal resistance. So, following Ohms Law, the current will be very high (as high as battery can supply)
Energizer
INDUSTRIAL
9V

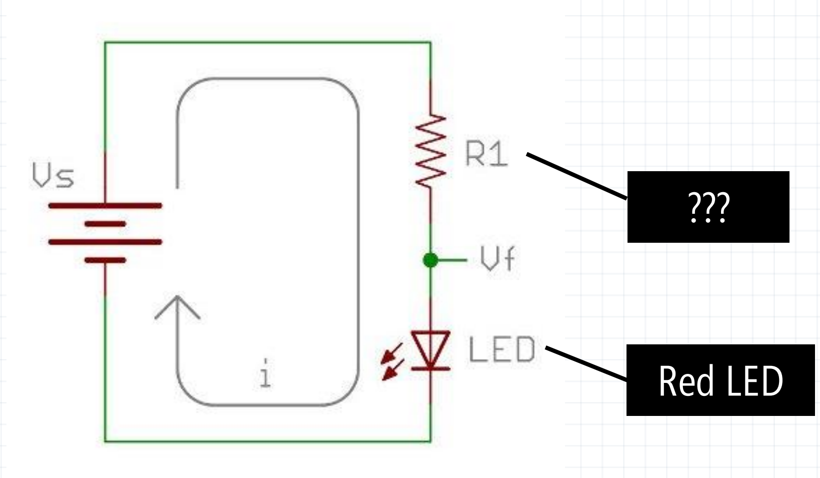
EASY WAY TO TEST IF AN LED STILL WORKS

Just use a coin cell battery (*e.g.*, a 3V) CR2025 or similar

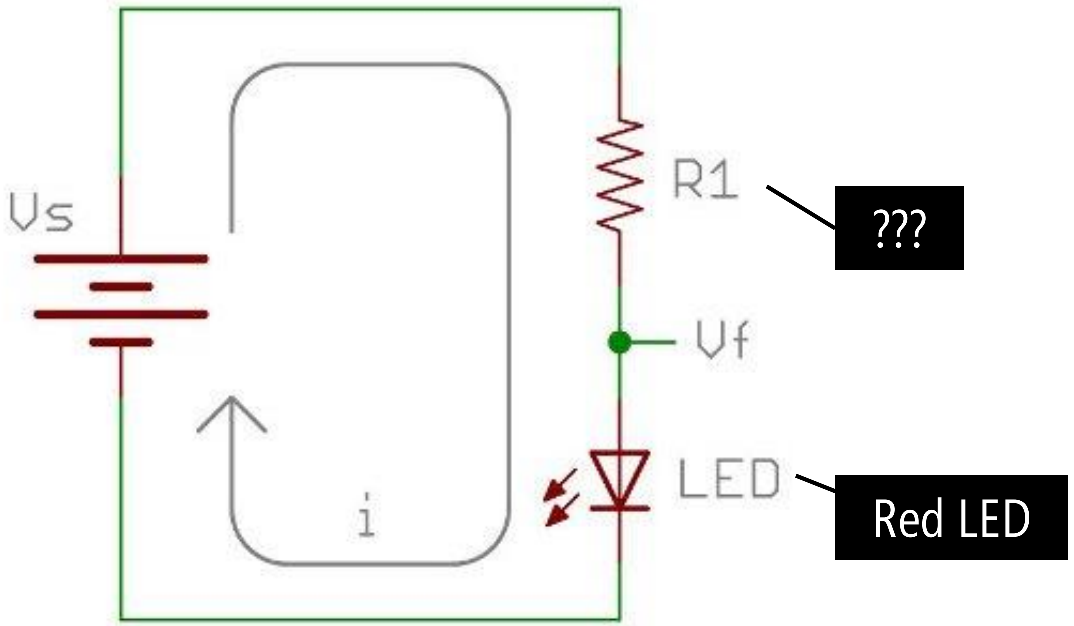
USING LEDS

HOW TO SELECT AN APPROPRIATE CURRENT LIMITING RESISTOR





HOW TO SELECT AN APPROPRIATE CURRENT LIMITING RESISTOR



We need to know three things:

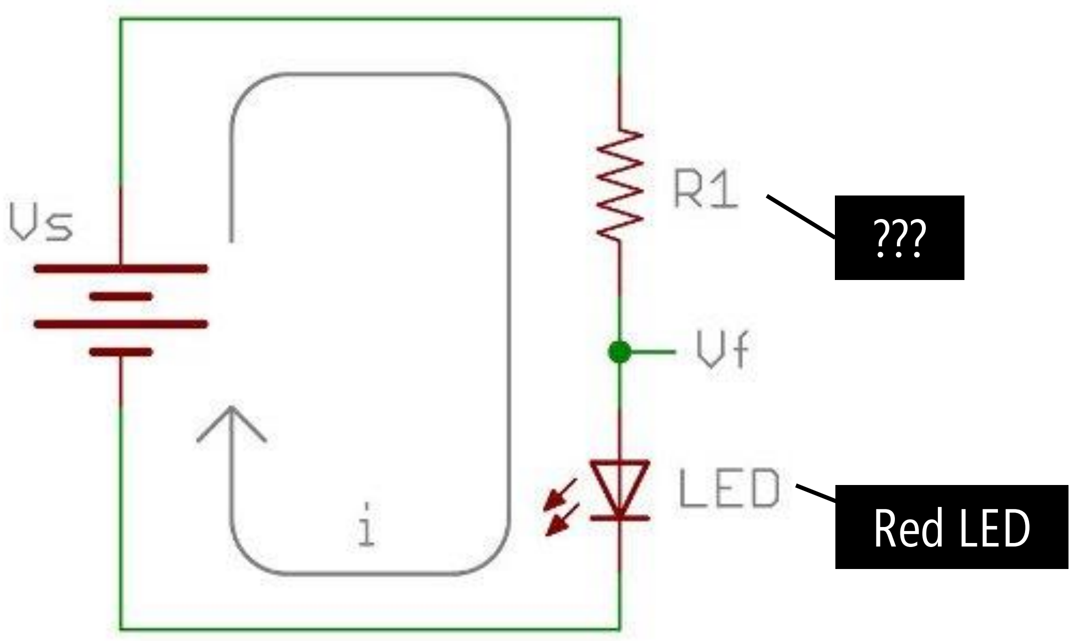
1. **LED forward current in Amps** (which is found in the LED datasheet). We will design our circuit around this desired current. Call this *i*.

2. **LED forward voltage in Volts** (again, consult the LED datasheet). Call this V_f

3. **The supply voltage.** Call this V_s. In our case, we are using a 9V battery, so V_s = 9V. Later, when we use Arduino, our V_s will shift to 5V.

Source: https://learn.sparkfun.com/tutorials/light-emitting-diodes-leds; https://www.sparkfun.com/quiz/60

HOW TO SELECT AN APPROPRIATE CURRENT LIMITING RESISTOR



With these three values, use this equation derived from Ohm's Law to find the value of the resistor:

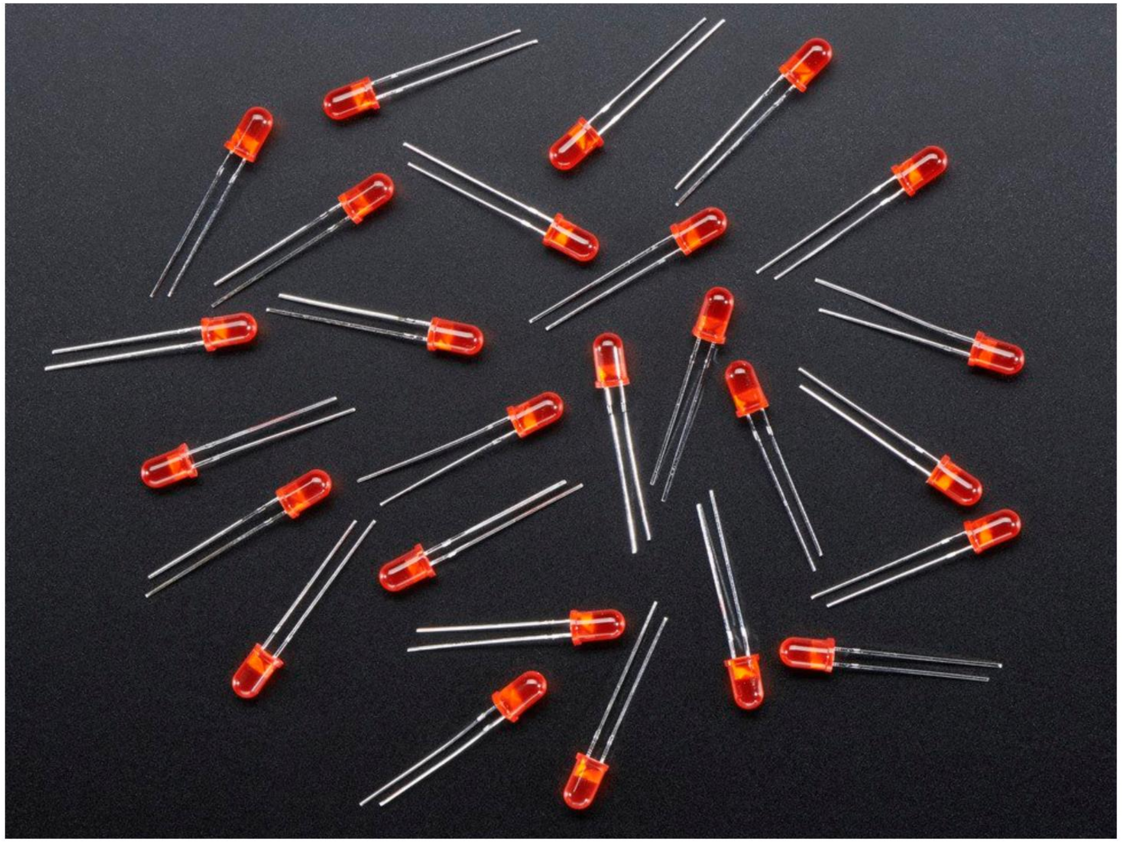
$$R = \frac{V_s - V_f}{i}$$

We need to know three things:

1. **LED forward current in Amps** (which is found in the LED datasheet). We will design our circuit around this desired current. Call this *i*.
2. **LED forward voltage in Volts** (again, consult the LED datasheet). Call this V_f
3. **The supply voltage.** Call this V_s. In our case, we are using a 9V battery, so V_s = 9V. Later, when we use Arduino, our V_s will shift to 5V.

USING LEDS

FINDING THE DATASHEET



Diffused Red 5mm LED (25 pack)

PRODUCT ID: 299

$4.00

OUT OF STOCK

Please enter your details below and we will send you an email when this item is back in stock. You will only be emailed about this product!

YOUR NAME

YOUR EMAIL

NOTIFY ME

ADD TO WISHLIST

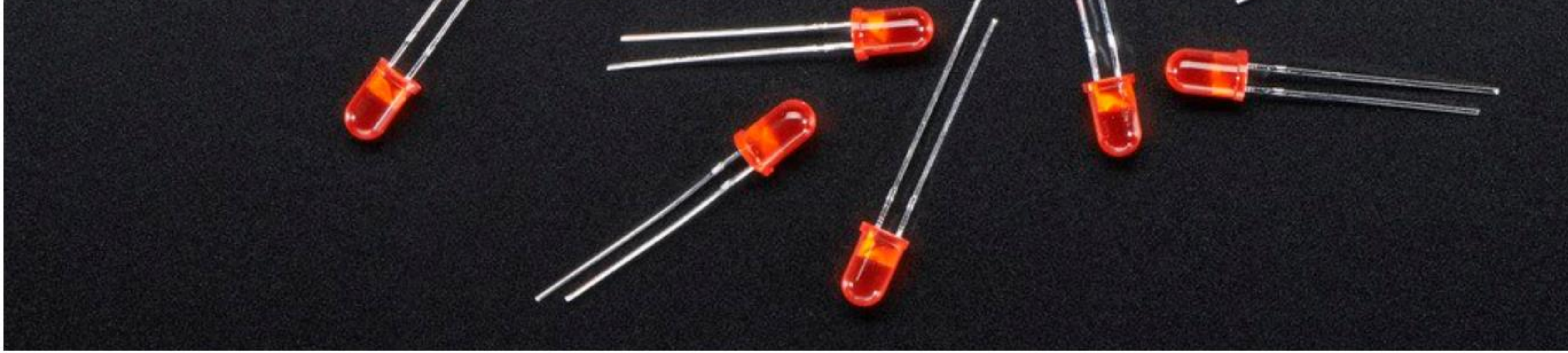
DESCRIPTION
TECHNICAL DETAILS
LEARN

DESCRIPTION

Need some indicators? We are big fans of these diffused red LEDs, in fact we use them exclusively in our kits. They are fairly bright so they can be seen in daytime, and from any angle. They go easily into a breadboard and will add that extra zing to your project.

- Pack of 25 diffused red LEDs
- 5mm diameter
- 660 nm wavelength
- 1.85-2.5V Forward Voltage, at 20mA current
- 250 mcd typical brightness
- Datasheet

If you need some help using LEDs, please read our "Introduction to using LEDs" tutorial for any electronics project.



DESCRIPTION

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Kingbright

T-1 3/4 (5mm) SOLID STATE LAMP

Part Number: WP7113SRD/D Super Bright Red

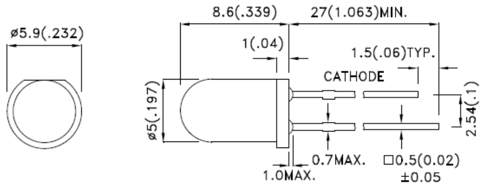
Features

- LOW POWER CONSUMPTION.
- POPULAR T-1 3/4 DIAMETER PACKAGE.
- GENERAL PURPOSE LEADS.
- RELIABLE AND RUGGED.
- LONG LIFE - SOLID STATE RELIABILITY.
- AVAILABLE ON TAPE AND REEL.
- RoHS COMPLIANT.

Description

The Super Bright Red source color devices are made with Gallium Aluminum Arsenide Red Light Emitting Diode.

Package Dimensions



Notes:
1. All dimensions are in millimeters (inches).
2. Tolerance is ±0.25(0.01") unless otherwise noted.
3. Lead spacing is measured where the leads emerge from the package.
4. Specifications are subject to change without notice.

Kingbright

Selection Guide

Part No.	Dice	Lens Type	Iv (mcd) [2] @ 20mA		Viewing Angle [1]
			Min.	Typ.	2θ1/2
WP7113SRD/D	Super Bright Red (GaAlAs)	RED DIFFUSED	180	250	30°

Notes:
1. θ1/2 is the angle from optical centerline where the luminous intensity is 1/2 the optical centerline value.
2. Luminous intensity/ luminous Flux: +/-15%.

Electrical / Optical Characteristics at TA=25°C

Symbol	Parameter	Device	Typ.	Max.	Units	Test Conditions
λpeak	Peak Wavelength	Super Bright Red	660		nm	IF=20mA
λD [1]	Dominant Wavelength	Super Bright Red	640		nm	IF=20mA
Δλ1/2	Spectral Line Half-width	Super Bright Red	20		nm	IF=20mA
C	Capacitance	Super Bright Red	45		pF	VF=0V;f=1MHz
VF [2]	Forward Voltage	Super Bright Red	1.85	2.5	V	IF=20mA
IR	Reverse Current	Super Bright Red		10	uA	VR = 5V

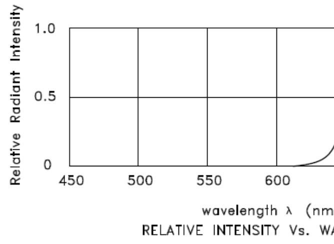
Notes:
1.Wavelength: +/-1nm.
2. Forward Voltage: +/-0.1V.

Absolute Maximum Ratings at TA=25°C

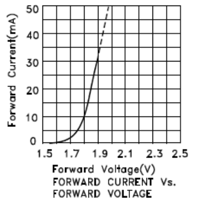
Parameter	Super Bright Red	Units
Power dissipation	75	mW
DC Forward Current	30	mA
Peak Forward Current [1]	155	mA
Reverse Voltage	5	V
Operating/Storage Temperature	-40°C To +85°C	
Lead Solder Temperature [2]	260°C For 3 Seconds	
Lead Solder Temperature [3]	260°C For 5 Seconds	

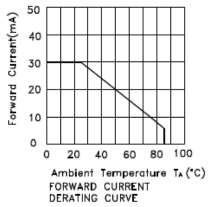
Notes:
1. 1/10 Duty Cycle, 0.1ms Pulse Width.
2. 2mm below package base.
3. 5mm below package base.

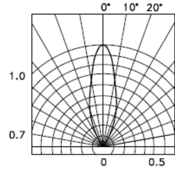
Kingbright



Super Bright Red WP7113SRD/D







SPATIAL DISTRIBUTION

Reading an LED Datasheet

https://www.sparkfun.com/datasheets/Components/LED/COM-09590-YSL-R531R3D-D2.pdf

ITEMS	Symbol	Absolute Maximum Rating	Unit
Forward Current	I_F	20	mA
Peak Forward Current	I_{FP}	30	mA
Suggestion Using Current	I_{SU}	16-18	mA
Reverse Voltage (VR=5V)	I_R	10	uA
Power Dissipation	P_D	105	mW
Operation Temperature	T_{OPR}	-40 ~ 85	℃
Storage Temperature	T_{STG}	-40 ~ 100	℃
Lead Soldering Temperature	T_{SOL}	Max. 260℃ for 3 Sec. Max. (3mm from the base of the expoxy bulb)	

Forward Current: how much current your LED will be able to handle continuously. In this case, 20mA.

Peak Forward Current: how much current the LED can sustain in short bursts. In this case, 30mA.

Suggestion Using Current: not all data sheets provide this, but this company recommends operating the LED at 16-18mA for best performance

Reverse Voltage: The maximum reverse voltage that the LED can sustain without damage (pay attention to this value if you often accidentally connect your LED anode to GND and cathode to VSS)

Power Dissipation: The amount of power in milliWatts that the LED can use before taking damage

[source: https://learn.sparkfun.com/tutorials/light-emitting-diodes-leds]

Reading an LED Datasheet

https://www.sparkfun.com/datasheets/Components/LED/COM-09590-YSL-R531R3D-D2.pdf

ITEMS	Symbol	Test condition	Min.	Typ.	Max.	Unit
Forward Voltage	V_F	I_F=20mA	1.8	---	2.2	V
Wavelenength (nm) or TC(k)	$\Delta\lambda$	I_F=20mA	620	---	625	nm
*Luminous intensity	I_V	I_F=20mA	150	---	200	mcd
50% Viewing Angle	$2\theta 1/2$	I_F=20mA	40	---	60	deg

Forward Voltage: The forward voltage is the voltage drop across the LED. You must reach this threshold to turn 'on' the LED. In this case, 1.8V to 2.2V

Wavelength: A precise way of explaining the color of the LED, in this case its 620-625nm

LED Brightness: A measure of how bright the LED can get. The unit, millicandela (mcd), is standard for measuring the intensity of a light source. This LED has a luminous intensity of 150-200, which would make for a good indicator light (super bright LEDs can have 160,000-180,000mcd).

Viewing Angle: Different style LEDs will incorporate different types of lenses, reflectors, or diffusers to concentrate light or spread it widely.

[source: https://learn.sparkfun.com/tutorials/light-emitting-diodes-leds; https://www.sparkfun.com/quiz/60]

Electrical / Optical Characteristics at TA=25°C

Symbol	Parameter	Device	Typ.	Max.	Units	Test Conditions
λpeak	Peak Wavelength	Super Bright Red	660		nm	IF=20mA
λD [1]	Dominant Wavelength	Super Bright Red	640		nm	IF=20mA
Δλ1/2	Spectral Line Half-width	Super Bright Red	20		nm	IF=20mA
C	Capacitance	Super Bright Red	45		pF	VF=0V,f=1MHz
VF [2]	Forward Voltage	Super Bright Red	1.85	2.5	V	IF=20mA
IR	Reverse Current	Super Bright Red		10	uA	VR = 5V

Notes:
1.Wavelength: +/-1nm.
2. Forward Voltage: +/-0.1V.

Absolute Maximum Ratings at TA=25°C

Parameter	Super Bright Red	Units
Power dissipation	75	mW
DC Forward Current	30	mA

Electrical / Optical Characteristics at TA=25°C

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Notes:
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Absolute Maximum Ratings at TA=25°C

Parameter	Super Bright Red	Units
Power dissipation	75	mW
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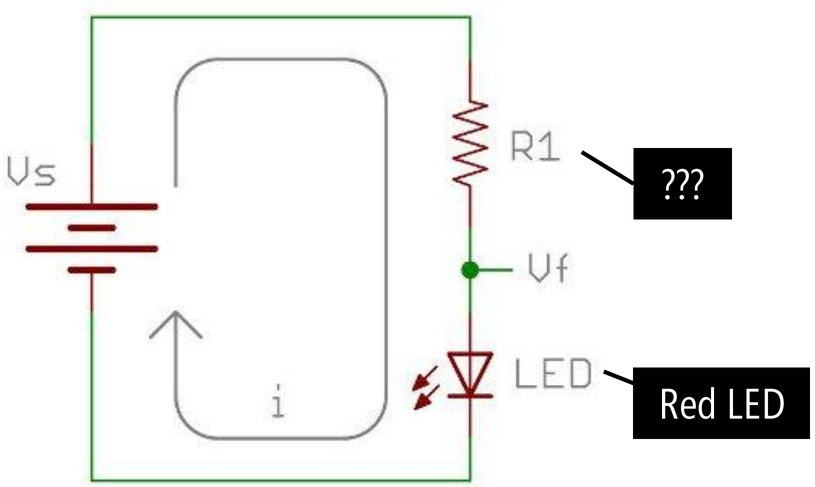
Peak Forward Current [1]	155	mA
Reverse Voltage	5	V
Operating/Storage Temperature	-40°C To +85°C	
Lead Solder Temperature [2]	260°C For 3 Seconds	
Lead Solder Temperature [3]	260°C For 5 Seconds	

Notes:
1. 1/10 Duty Cycle, 0.1ms Pulse Width.
2. 2mm below package base.
3. 5mm below package base.

SPEC NO: DSAF2433 REV NO: V.2 DATE: MAY/11/2007 PAGE: 2 OF 6



Recall that our equation for finding the value of the current limiting resistor is:

$$R = \frac{V_s - V_f}{i}$$

Let's plugin some values:

$$R = \frac{9V - 2V}{0.02A}$$

Which results in:

$$R = 350\Omega$$

USING LEDS
TWO GOTCHAS!

Electrical / Optical Characteristics at TA=25°C

Symbol	Parameter	Device	Typ.	Max.	Units	Test Conditions
λpeak	Peak Wavelength	Super Bright Red	660		nm	I_F=20mA
λD [1]	Dominant Wavelength	Super Bright Red	640		nm	I_F=20mA
Δλ1/2	Spectral Line Half-width	Super Bright Red	20		nm	I_F=20mA
C	Capacitance	Super Bright Red	45		pF	V_F=0V;f=1MHz
V_F [2]	Forward Voltage	Super Bright Red	1.85	2.5	V	I_F=20mA
I_R	Reverse Current	Super Bright Red		10	uA	V_R = 5V

Notes:
1.Wavelength: +/-1nm.
2. Forward Voltage: +/-0.1V.

Absolute Maximum Ratings at TA=25°C

Parameter	Super Bright Red	Units
Power dissipation	75	mW
DC Forward Current	30	mA
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Lead Solder Temperature [2]	260°C For 3 Seconds	
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Notes:
1. 1/10 Duty Cycle, 0.1ms Pulse Width.
2. 2mm below package base.
3. 5mm below package base.

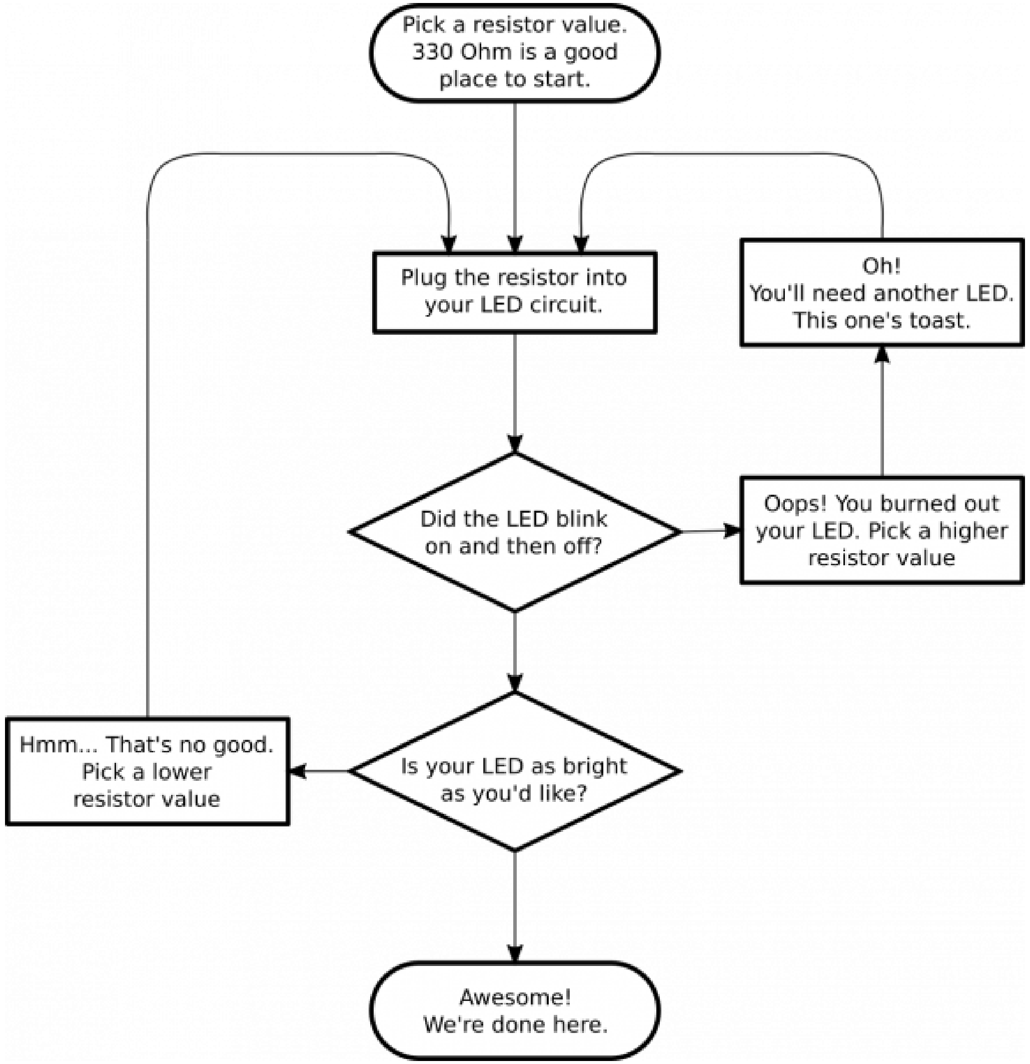
If you exceed the **Peak Forward Current**, your LED will **burnout**!

Typically, if you hook up your LED in reverse (*i.e.*, cathode to positive, anode to negative), nothing will happen. However, if you accidentally do this and **exceed the Reverse Voltage** (5V in this case), again you can damage your LED.

OK, that's the formal way. But typically, most LEDs have forward currents of 20-35mA so **starting with a ~200-330Ω resistor** is a good rule of thumb.

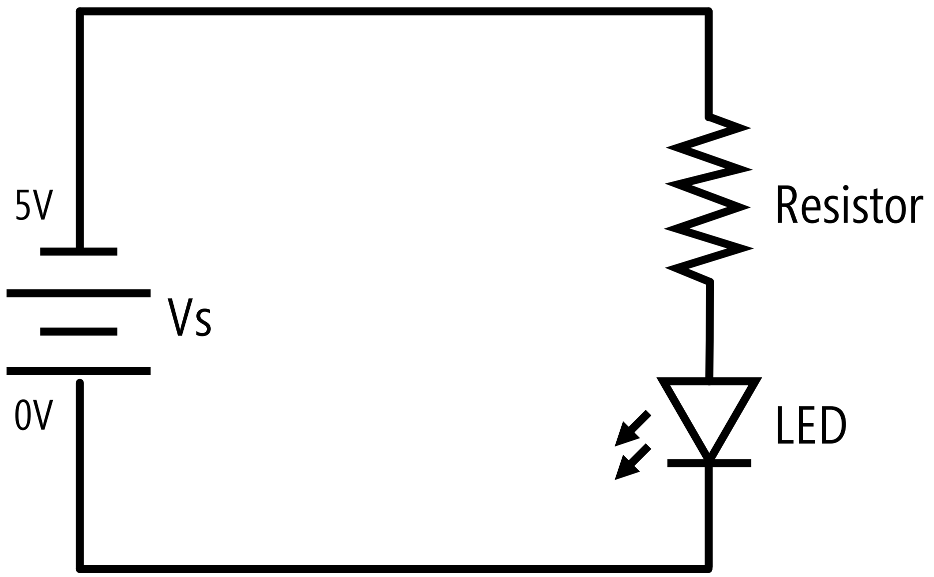
HOW TO SELECT AN APPROPRIATE CURRENT LIMITING RESISTOR

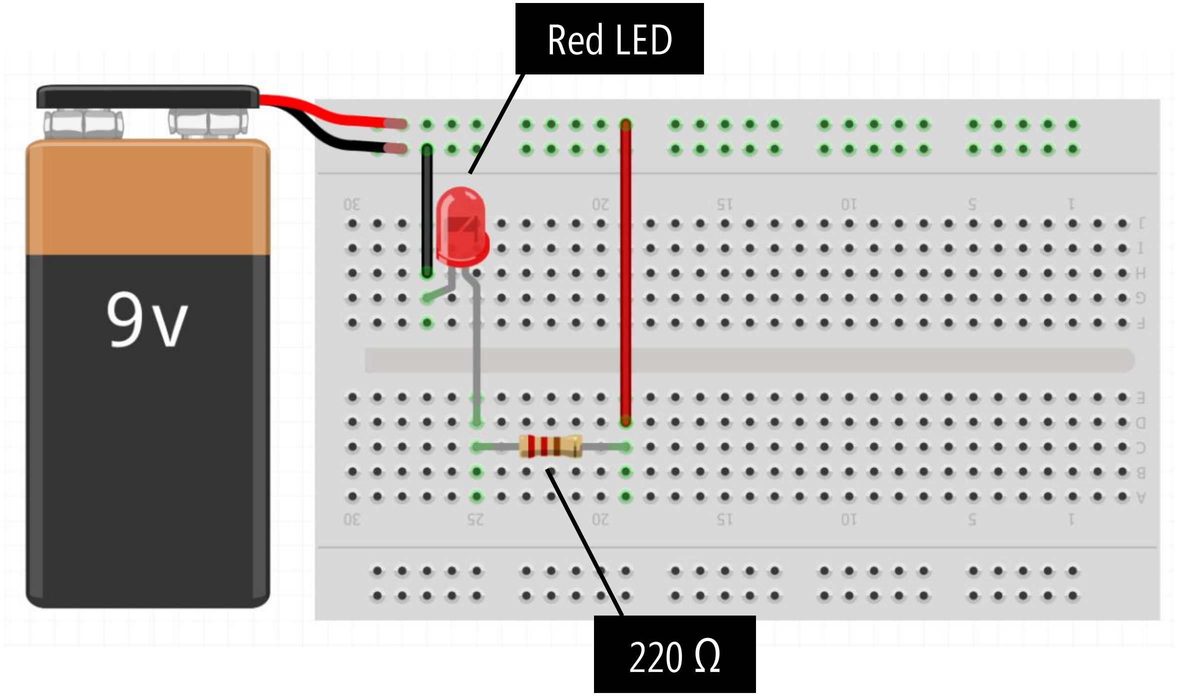
THE TRIAL AND ERROR METHOD



Source: https://learn.sparkfun.com/tutorials/light-emitting-diodes-leds

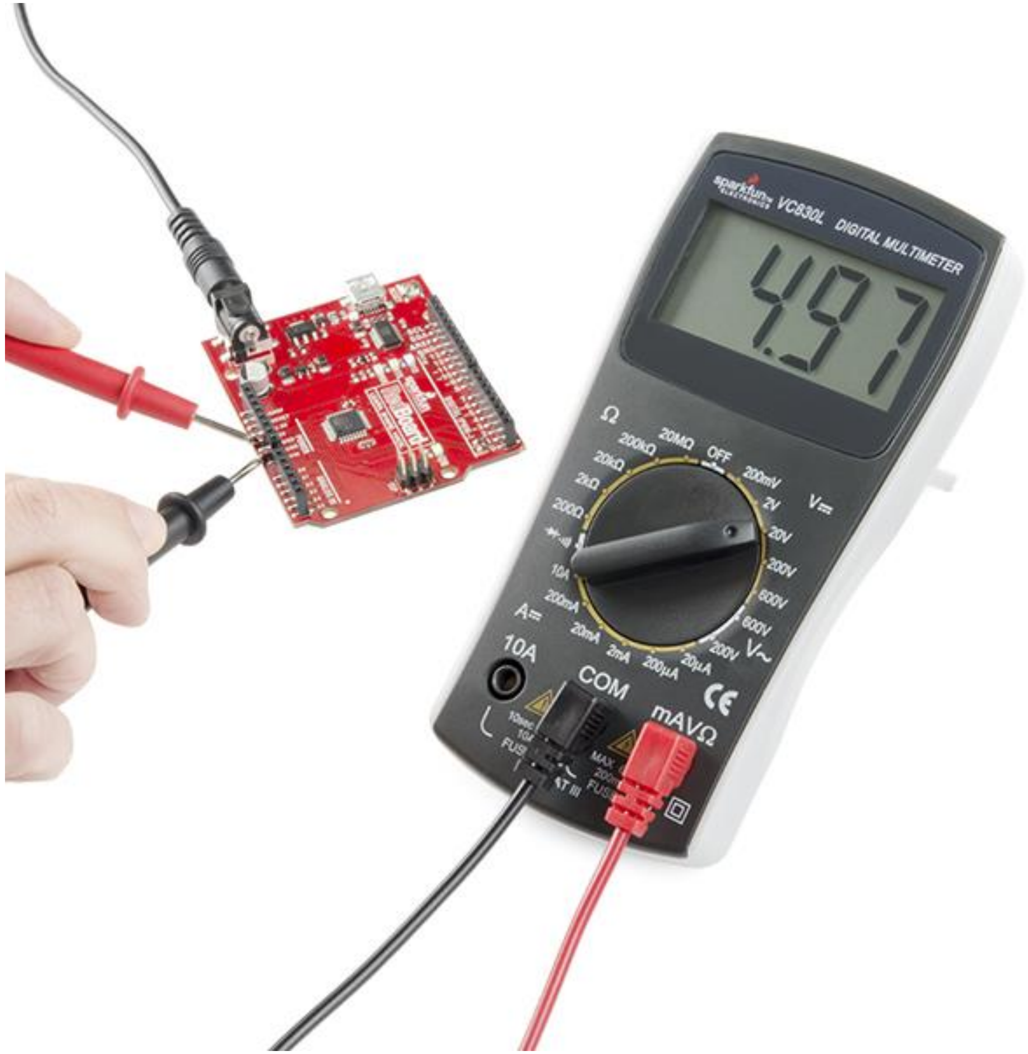
EXERCISE: HOW MUCH CURRENT THROUGH LED?





Let's measure it empirically using a multimeter… but first, an introduction

YOU CAN MEASURE CIRCUITS WITH A MULTIMETER



Resistance

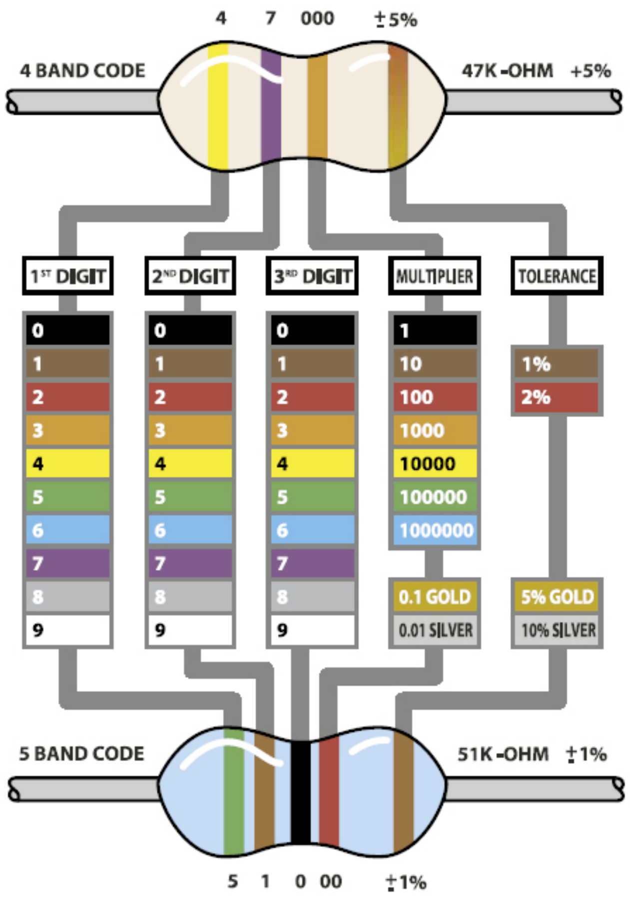
Voltage

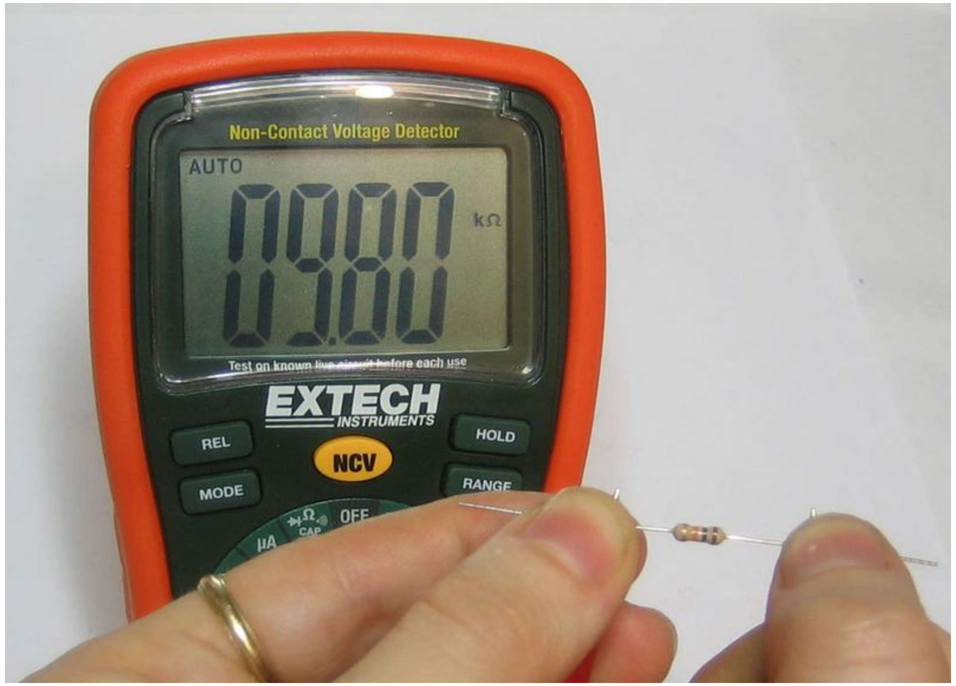
Current

Continuity (short testing)

MEASURE A RESISTOR

You can interpret color codes on a resistor or use a multimeter





This 10KΩ resistor is really 9.80K Ω

Source: https://learn.adafruit.com/multimeters/resistance

EXERCISE: MEASURE RESISTANCE

1. Switch the multimeter to the **measure resistance** mode

2. Place each probe end on one leg of the resistor (it doesn't matter which because resistors have no polarity)

MEASURING RESISTANCE

You can only test resistance when the device you're testing is not powered. Resistance testing works by poking a little voltage into the circuit and seeing how much current flows, its perfectly safe for any component but if its powered there is already voltage in the circuit, and you will get incorrect readings

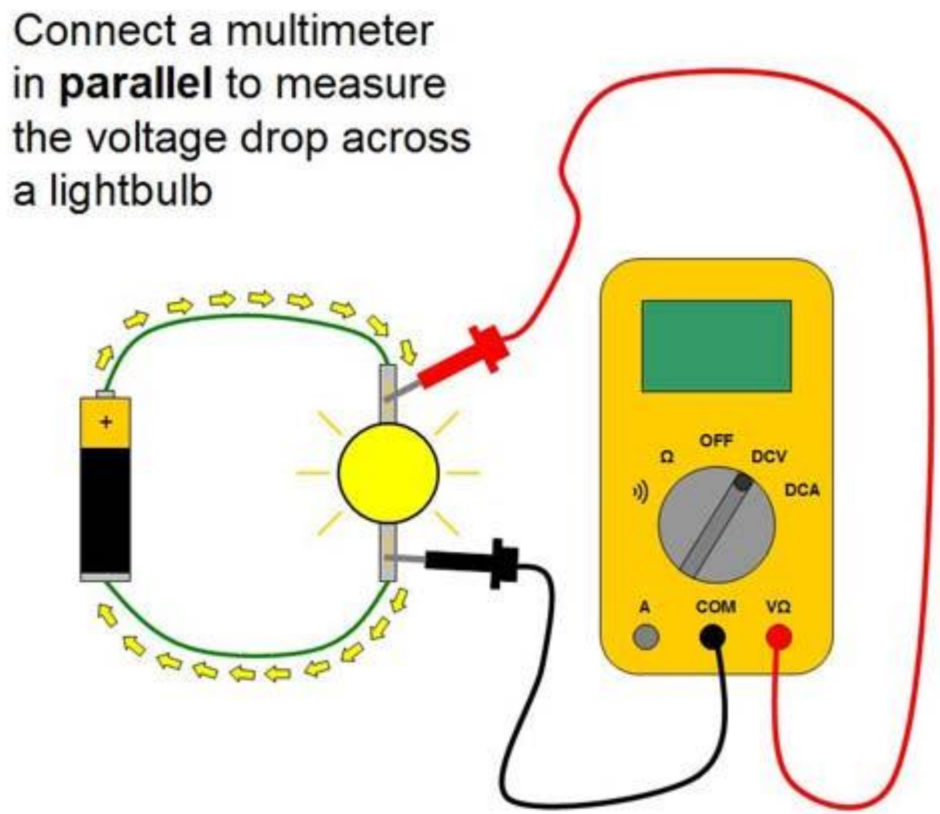
You can only test a resistor before it has been soldered/inserted into a circuit. If you measure it in the circuit you will also be measuring everything connected to it. In some instances this is OK but I would say that in the vast majority it is not. If you try, you will get incorrect readings and that's worse than no reading at all.

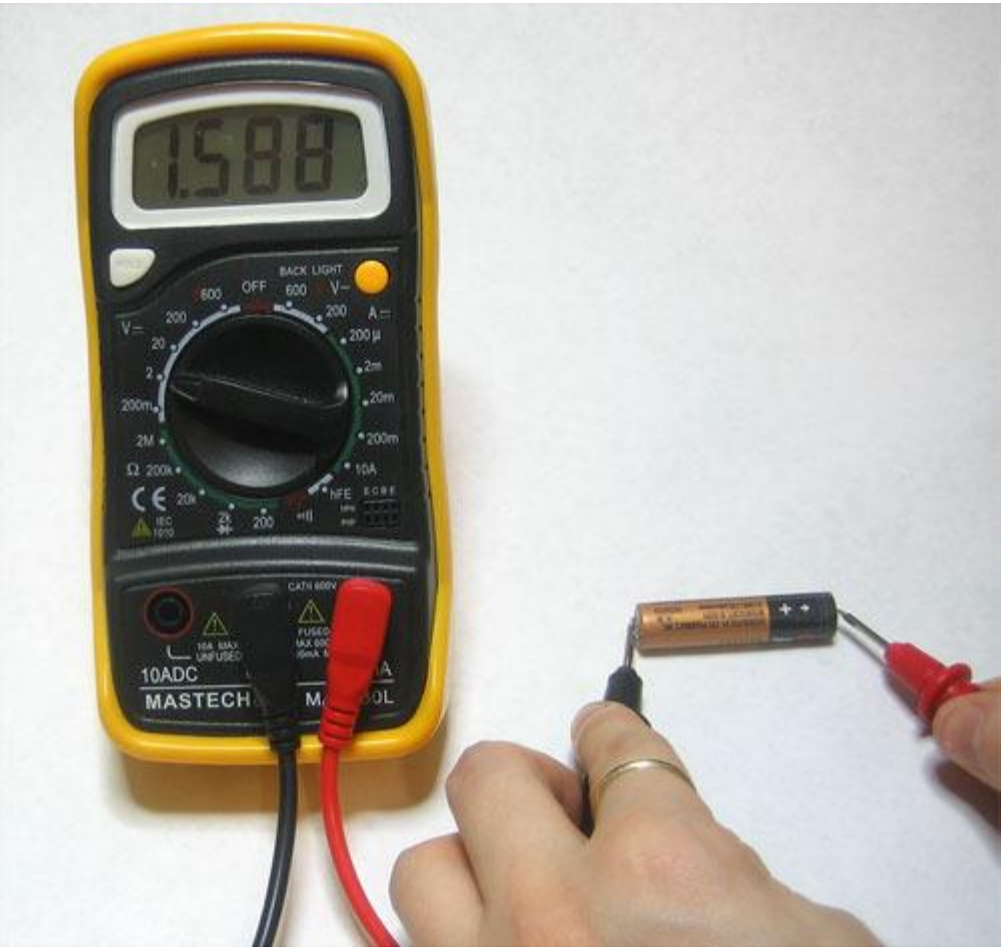
Resistance is non-directional, you can switch probes and the reading will be the same.

If you have a ranging meter (as most inexpensive ones are), you'll need to keep track of what range you are in. Otherwise, you will get strange readings, like OL or similar, or you may think you're in KΩ when really you're in MΩ. This is a big problem for beginners so be careful!

[source: https://learn.adafruit.com/multimeters/resistance]

MEASURING VOLTAGE





This 1.5V battery reads 1.588V. Why? The 1.5V written on the battery is a nominal voltage—or the "average" you may expect from the battery. In reality, an alkaline battery starts out higher, then slowly drifts down to 1.3V, then finally to 1.0V and even lower.

Source: https://learn.adafruit.com/multimeters/resistance; http://www.sciencebuddies.org/science-fair-projects/multimeters-tutorial.shtml

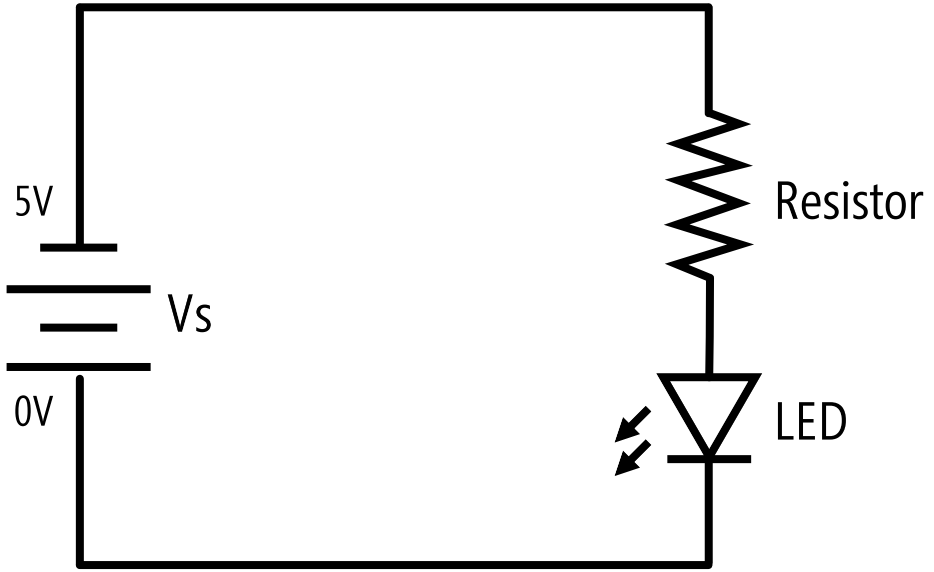
MEASURING VOLTAGE: SWITCH MULTIMETER TO V

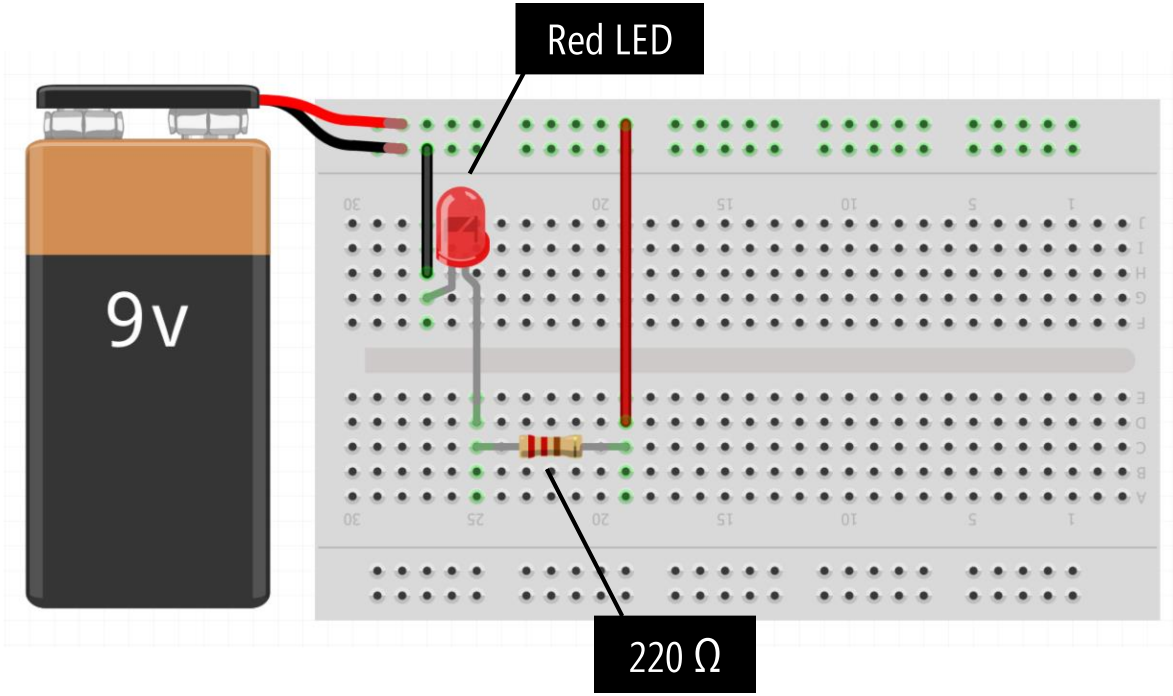
Figure 1-54. *Each meter has a different way to measure volts DC. The manually adjusted meter (top) requires you to move a slider switch to "DC" and then choose the highest voltage you want to measure: In this case, the selected voltage is 20 (because 2 would be too low). Using the autoranging RadioShack meter, you set it to "V" and the meter will figure out which range to use.*

Figure 1-53

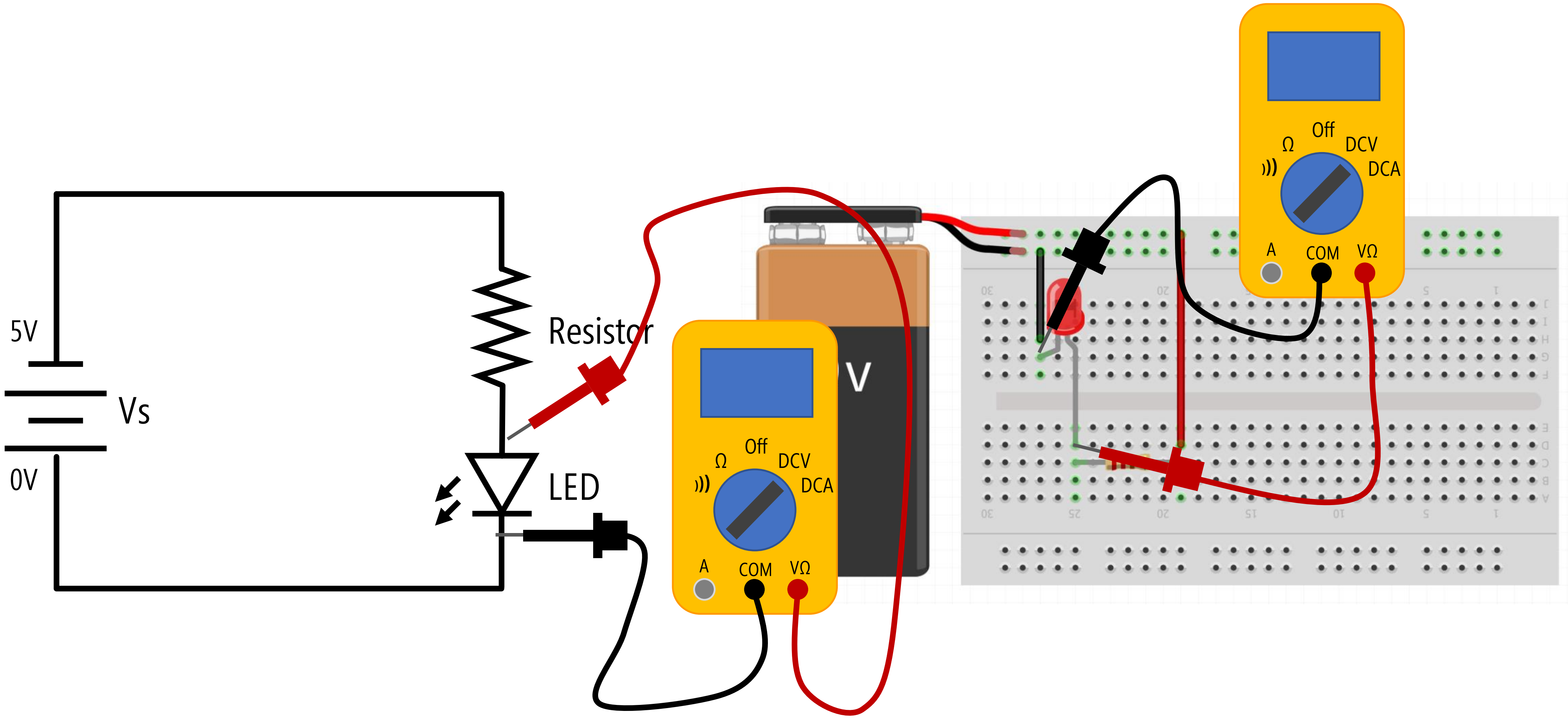
Figure 1-52

EXERCISE: WHAT'S THE VOLTAGE DROP ACROSS THE LED?





EXERCISE: WHAT'S THE VOLTAGE DROP ACROSS THE LED?



MEASURING VOLTAGE TIPS 1

You can only test voltage when the circuit is powered. If there is no voltage coming in (power supply) then there will be no voltage in the circuit to test! It must be plugged in (even if it doesn't seem to be working)

Voltage is always measured between two points. By definition, voltage is the *difference* between two points. There is no way to measure voltage with only one probe, it is like trying to check continuity with only one probe. You must have two probes in the circuit. If you are told to test at a point or read the voltage at this or that location what it really means is that you should put the negative (reference, ground, black) probe at ground (which you must determine by a schematic or somewhere else in the instructions) and the positive (red) probe at the point you would like to measure.

If you're getting odd readings, use a reference voltage (even a 9V battery is a reasonable one) to check your voltage readings. Old meter batteries and wonky meters are the bane of your existence but they will eventually strike! Good places to take reference voltages are regulated wall plugs such as those for cell phones. Two meters might also be good :)

[source: https://learn.adafruit.com/multimeters/voltage]

MEASURING VOLTAGE TIPS 2

Voltage is directional. If you measure a battery with the red/positive probe on the black/negative contact and the black probe on the positive contact you will read a negative voltage. If you are reading a negative voltage in your ciruit and you're nearly positive (ha!) that this cannot be, then make sure you are putting the black probe on the reference voltage (usually ground)

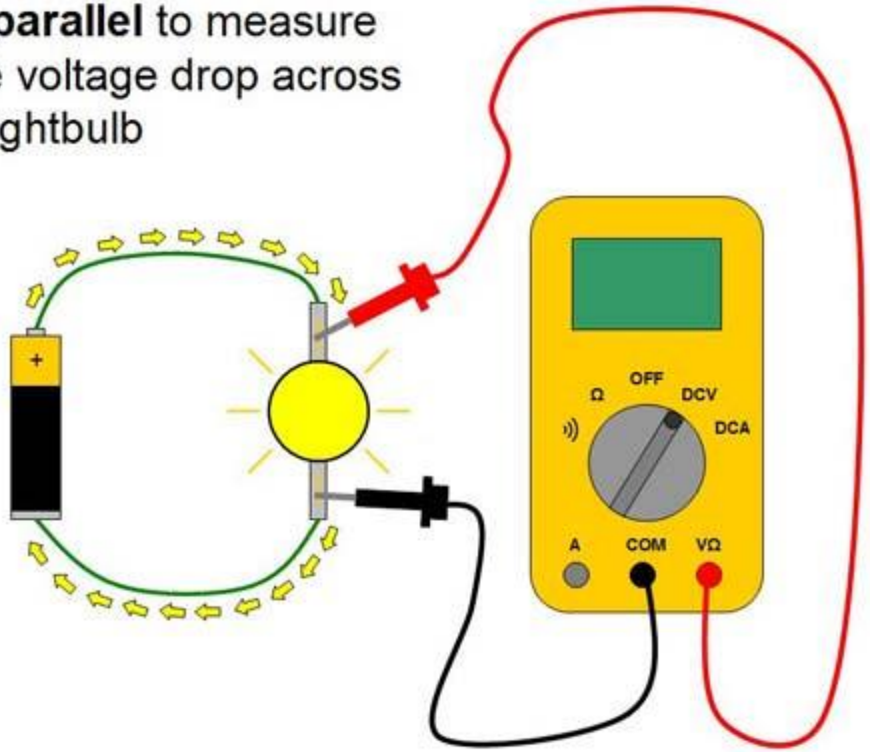
DC voltage and AC voltage are very different. Make sure you are testing the right kind of voltage. This may require pressing a mode button or changing the dial. Unless otherwise indicated, assume DC voltages

Multimeters have different input impedences that affect readings of high impedence circuits. For example, measuring a sensor that has 1Mohm impedence with a 1Mohm impedence meter will give you only half the correct reading

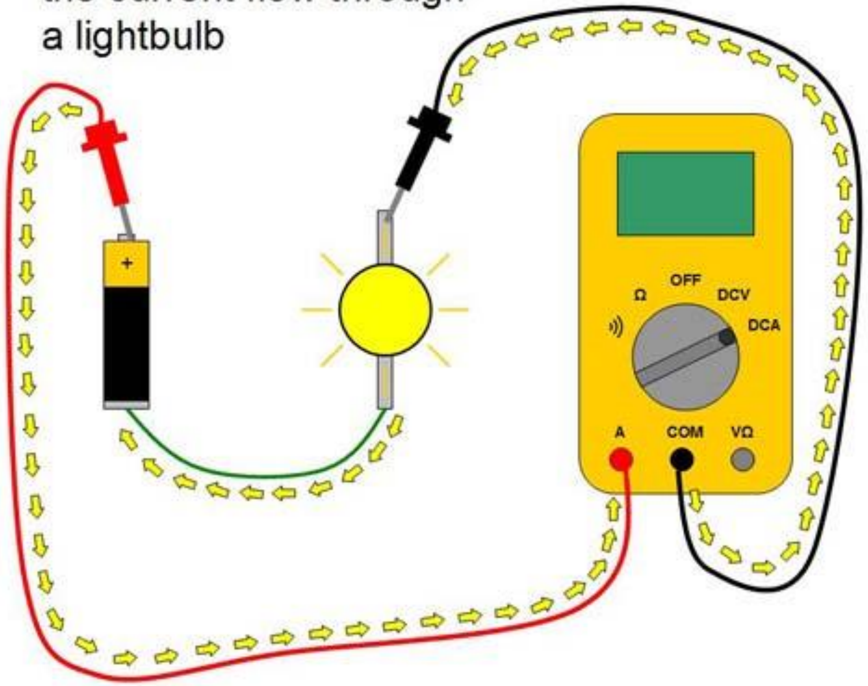
[source: https://learn.adafruit.com/multimeters/voltage]

MEASURING VOLTAGE VS. CURRENT

Connect a multimeter in **parallel** to measure the voltage drop across a lightbulb



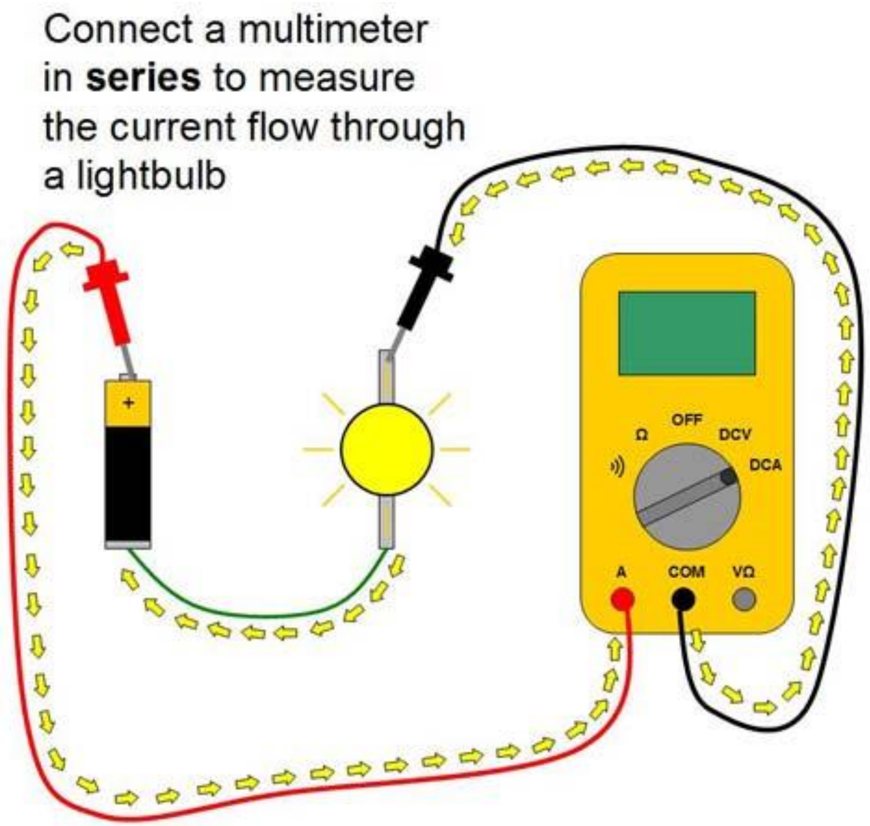
Connect a multimeter in **series** to measure the current flow through a lightbulb

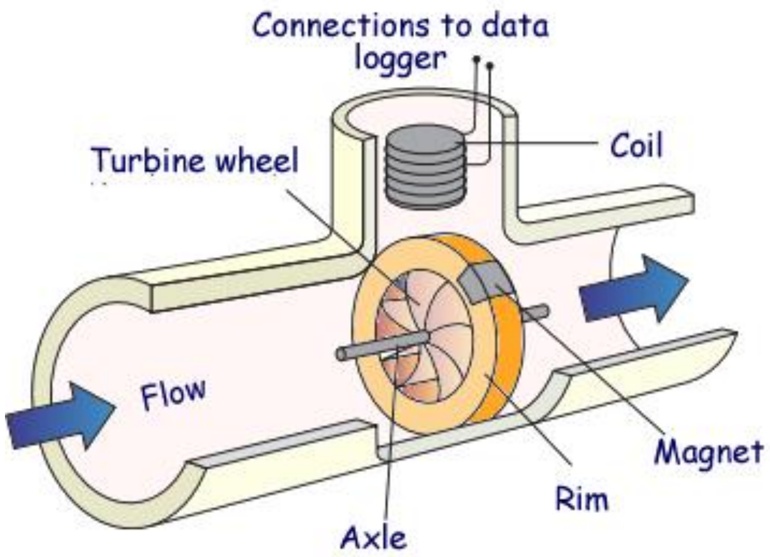


Source: https://learn.adafruit.com/multimeters/resistance; http://www.sciencebuddies.org/science-fair-projects/multimeters-tutorial.shtml

MEASURING CURRENT

When measuring current, think of the multimeter as a little turbine sensor for electrons. It needs to be inline (in series) in order to measure flow!





MEASURING CURRENT: CONFIGURE FOR MEASUREMENT

Figure 1-58. *Any meter will blow its internal fuse if you try to make it measure too high an amperage. In our circuit, this is not a risk as long as you keep the potentiometer in the middle of its range. Choose "mA" for milliamps and remember that the meter displays numbers that mean thousandths of an amp.*

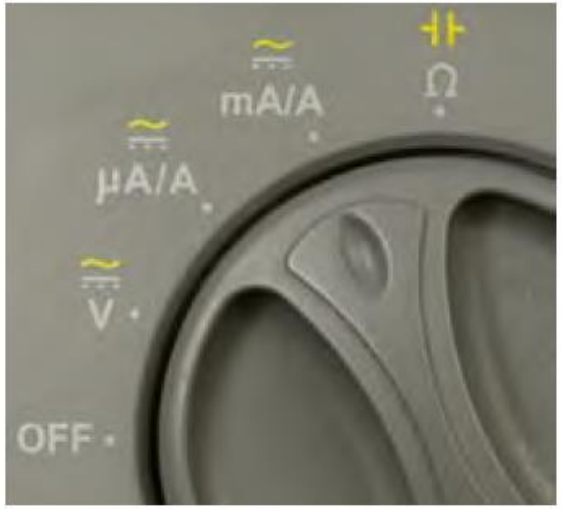
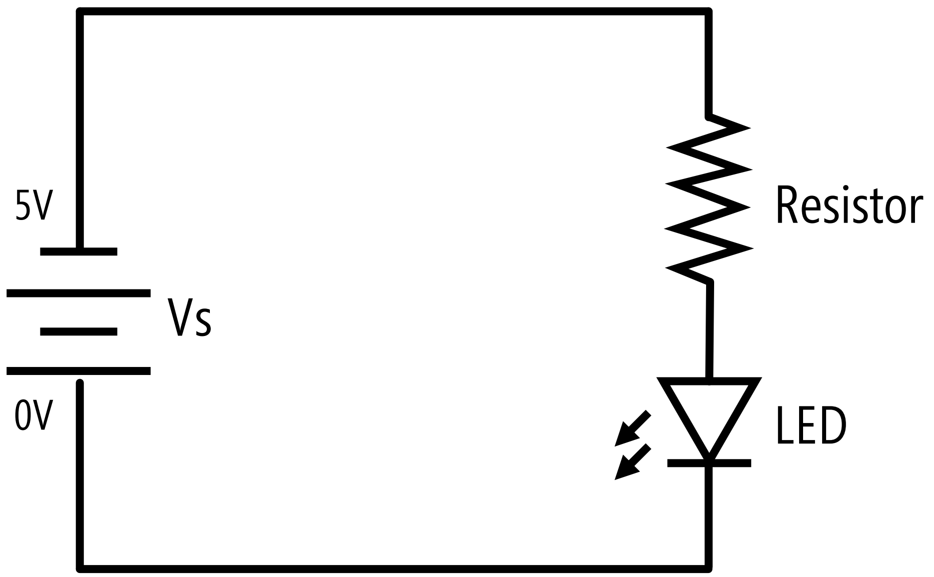
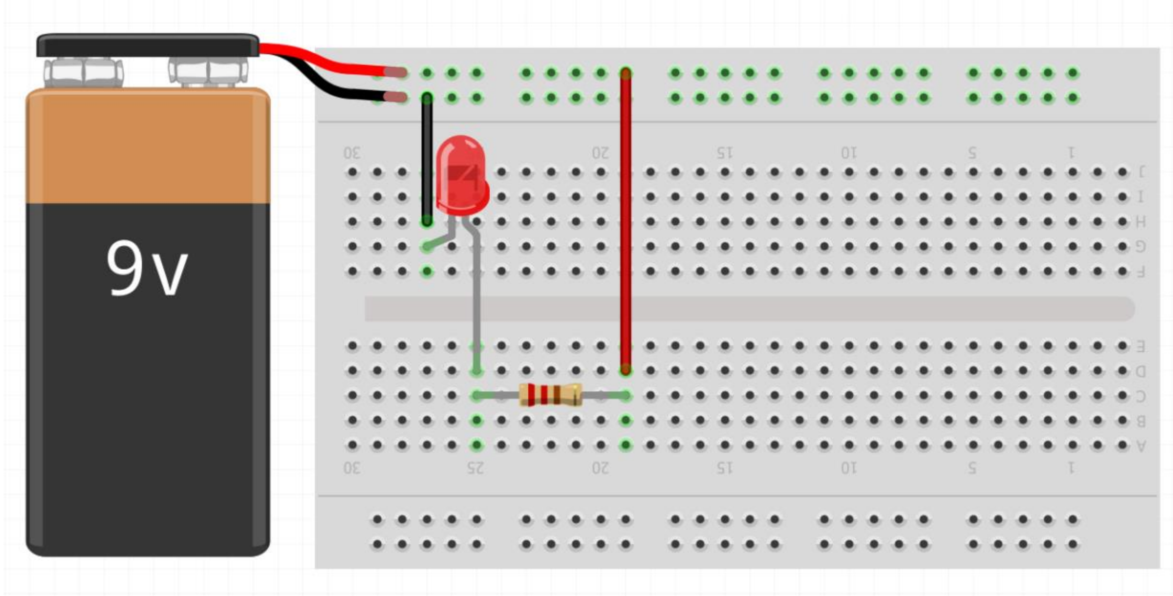


Figure 1-59

EXERCISE: HOW MUCH CURRENT THROUGH LED?

You'll have to slightly rewire this circuit so that the current passes through the multimeter





EXERCISE: HOW MUCH CURRENT THROUGH LED?

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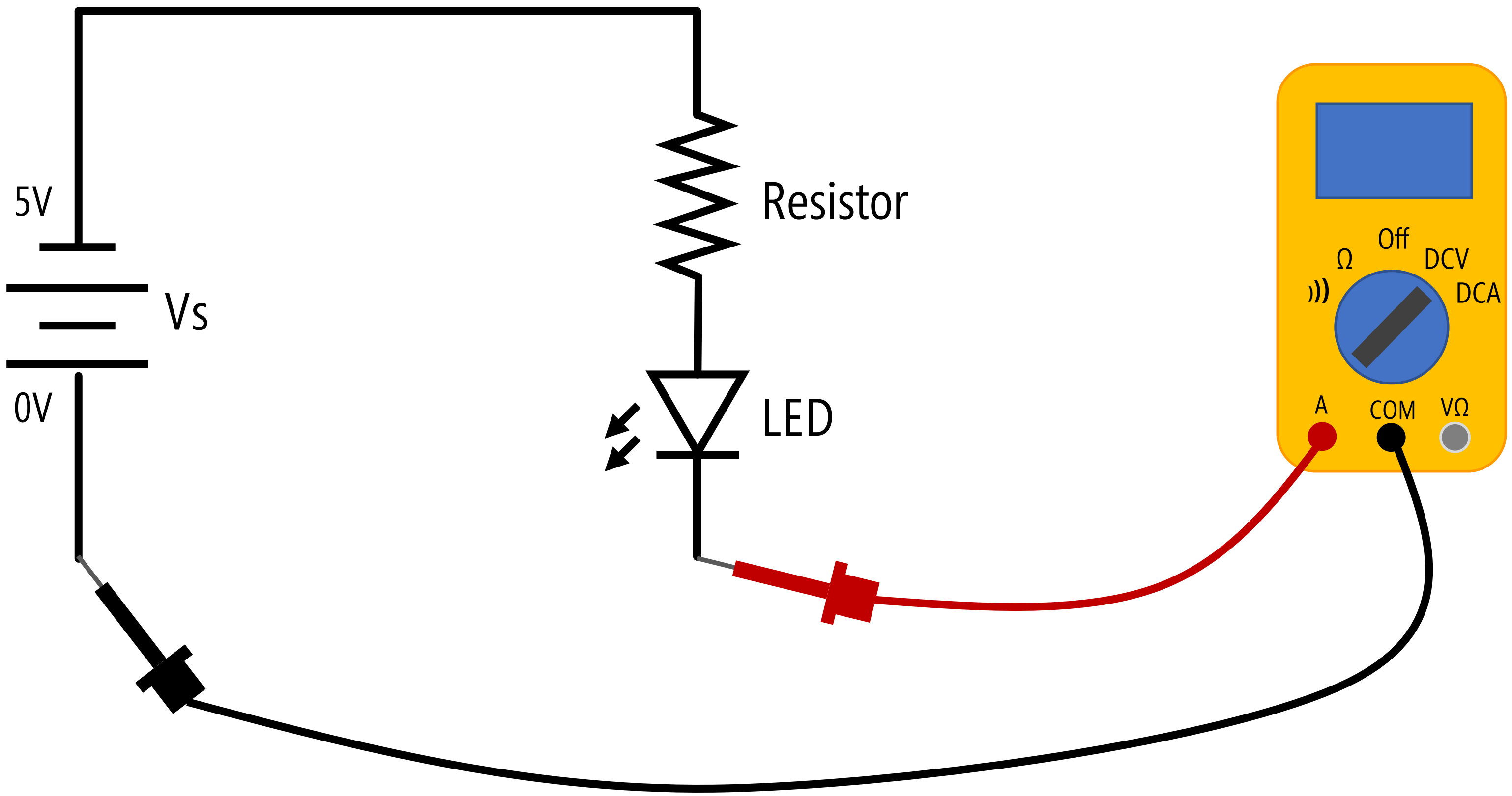
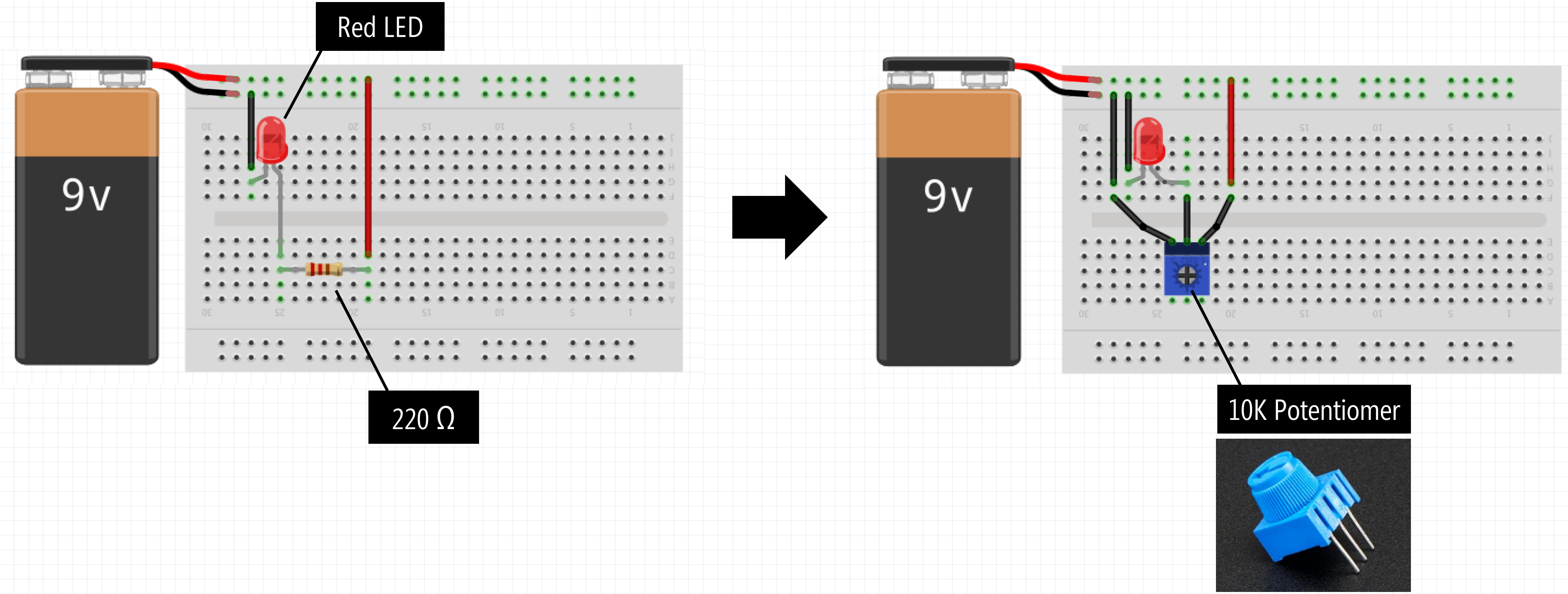


ACTIVITY

SWAP THE FIXED RESISTOR WITH A POTENTIOMETER



Potentiometers are Everywhere!

Used to adjust sensitivity, balance, input, output (especially in audio equipment)

VARIABLE RESISTOR

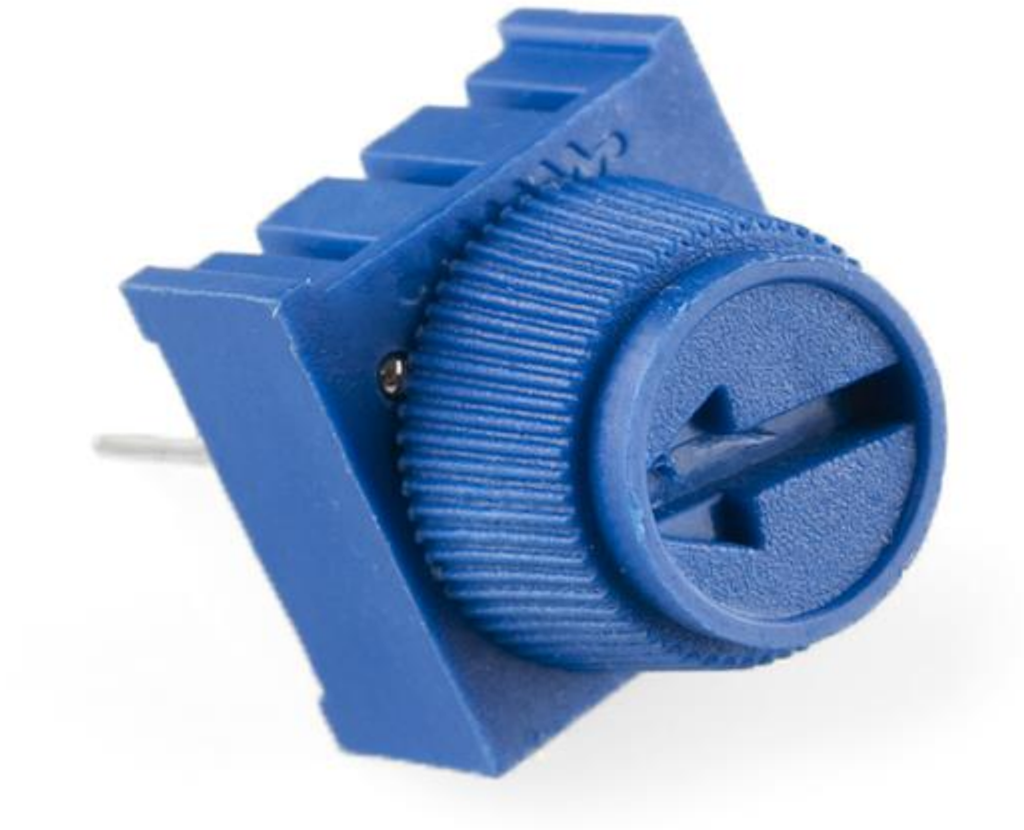
HUGE VARIETY OF POTENTIOMETERS

VARIABLE RESISTORS

SLIDE POTENTIOMETERS

[source: https://www.sparkfun.com/products/11620]

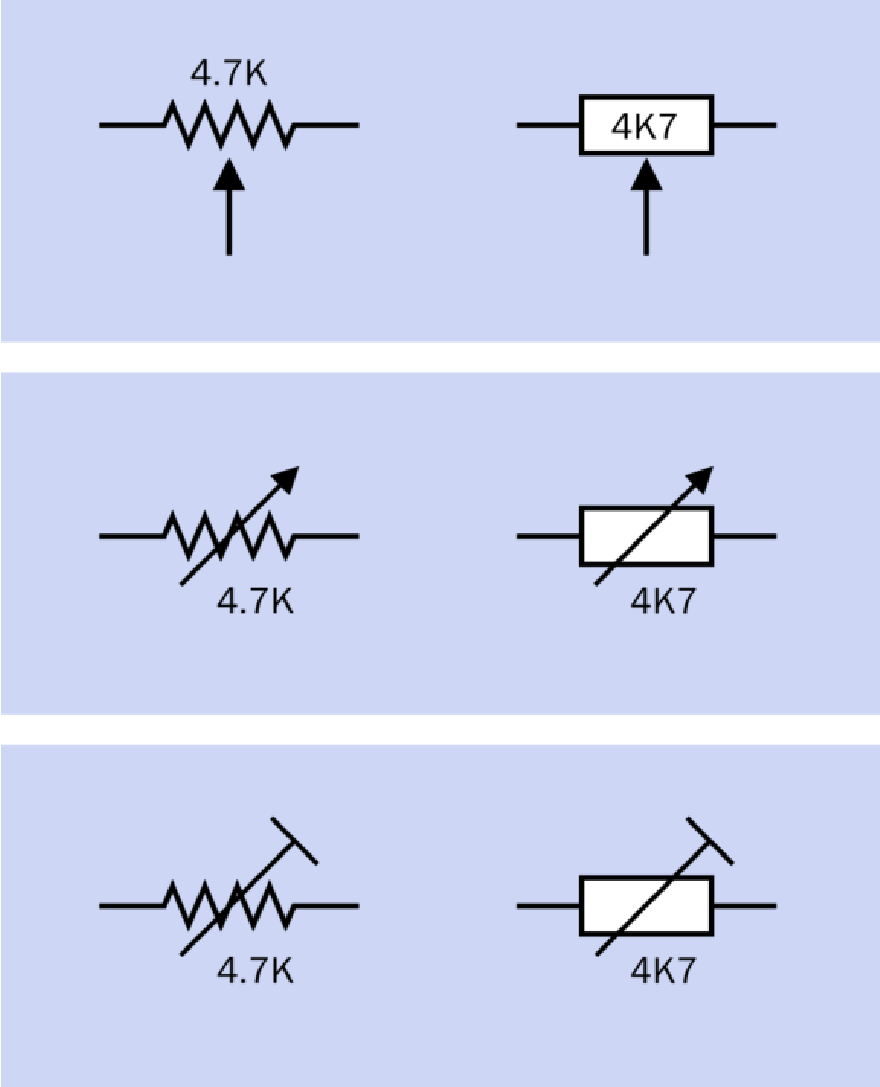
BREADBOARD-FRIENDLY TRIMPOT



[source: https://www.sparkfun.com/products/9806?_ga=1.88313947.1111827570.1420822056]

VARIABLE RESISTORS

POTENTIOMETER SCHEMATIC SYMBOLS

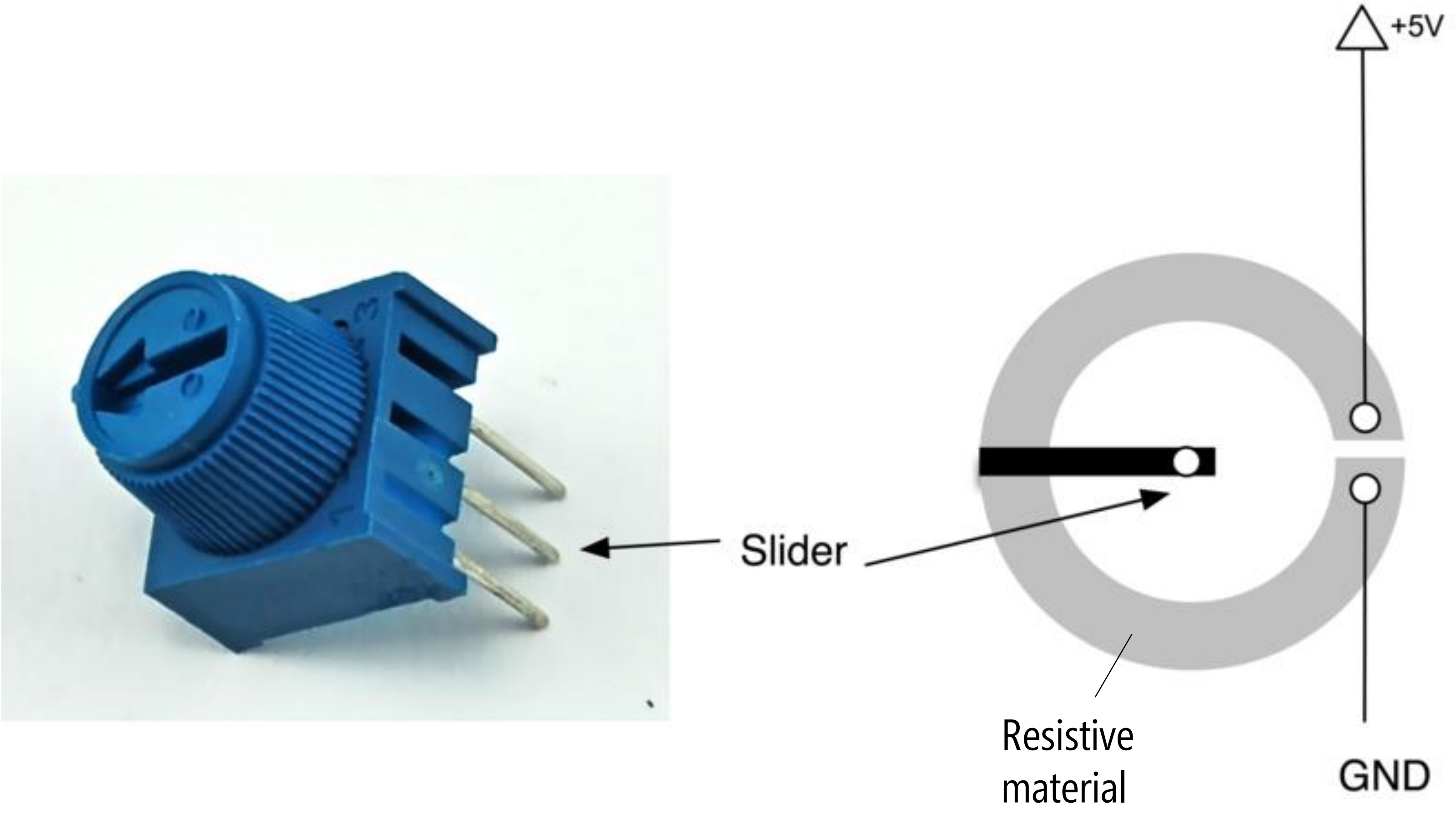


American Symbol European Symbol

[source: Platt, Encyclopedia of Electronic Components: Volume 1, 2012]

WHAT IS A POTENTIOMETER

A potentiometer is a variable resistor. Twist the dial to change the resistance!



Source: https://learn.adafruit.com/adafruit-arduino-lesson-8-analog-inputs/variable-resistors-pots

WHAT IS A POTENTIOMETER

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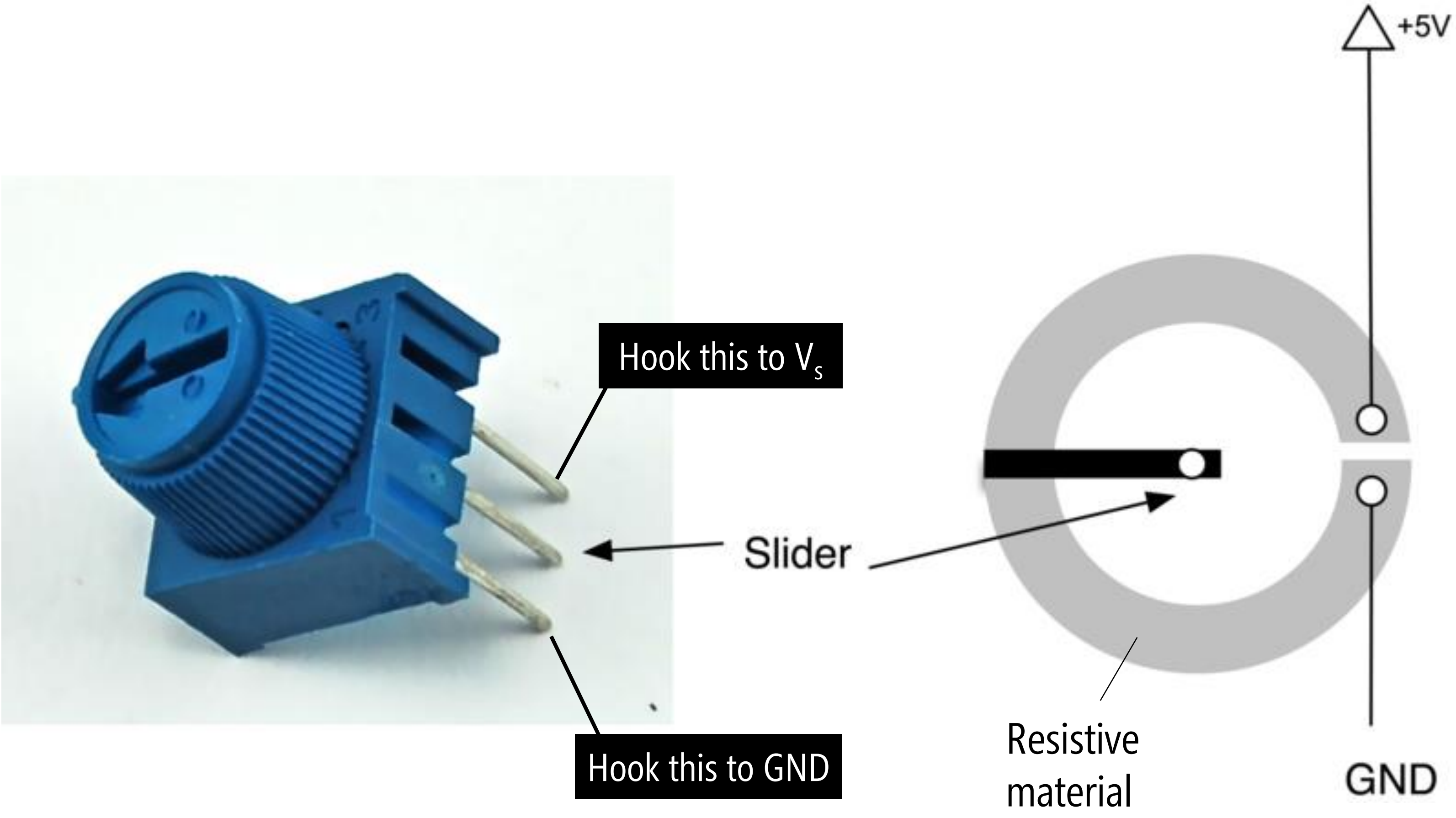
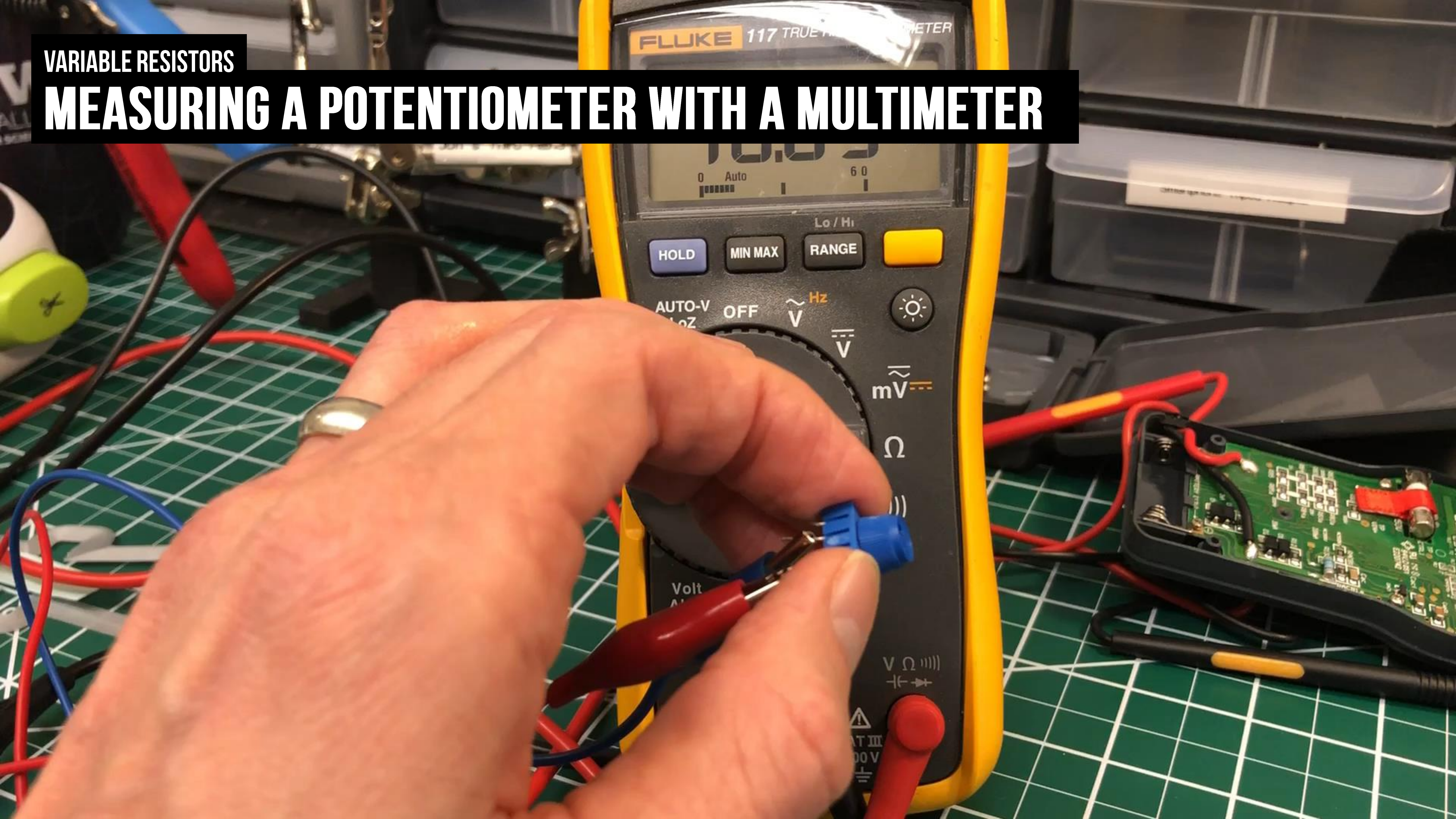
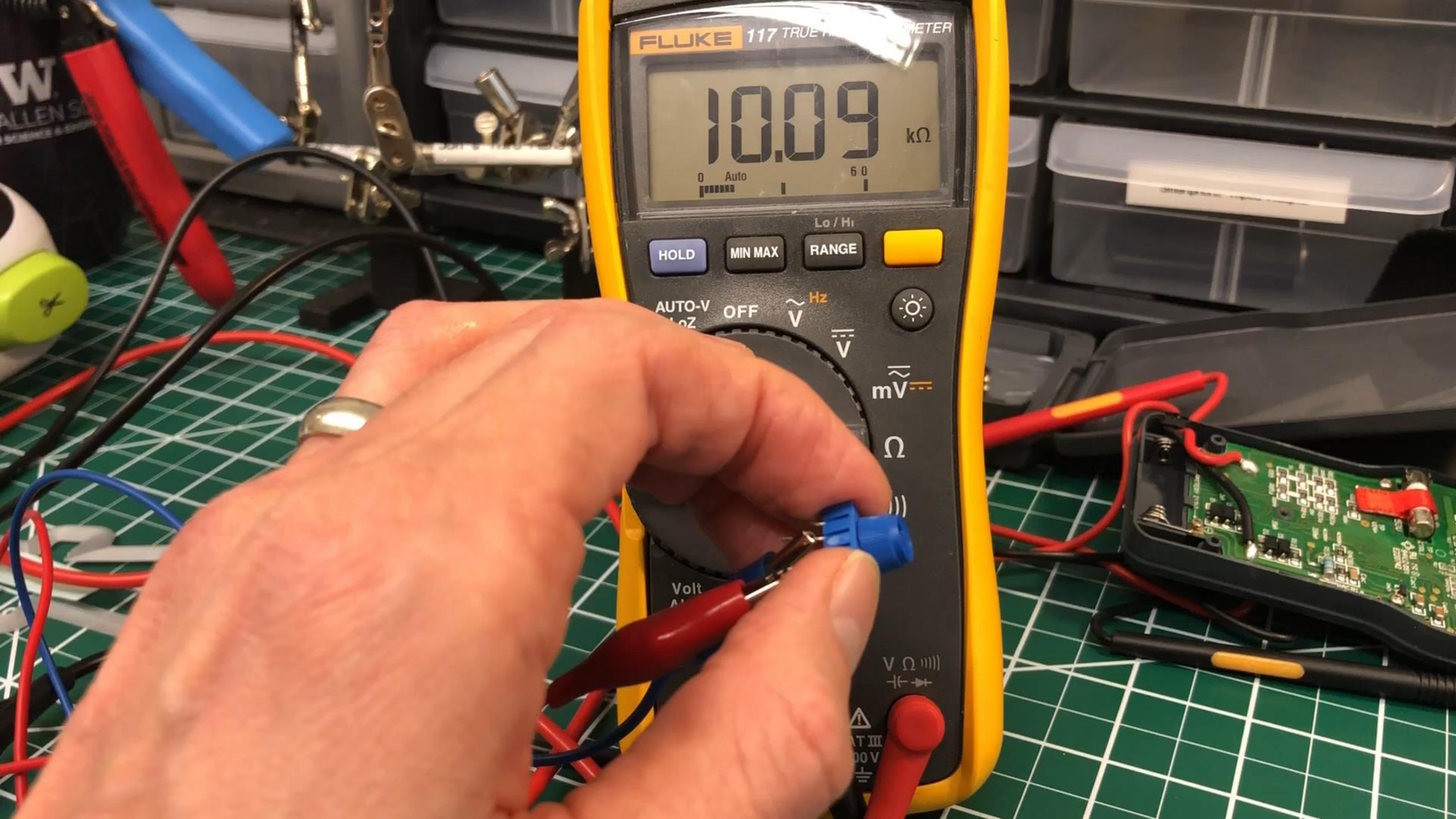


Source: https://learn.adafruit.com/adafruit-arduino-lesson-8-analog-inputs/variable-resistors-pots

VARIABLE RESISTORS

MEASURING A POTENTIOMETER WITH A MULTIMETER

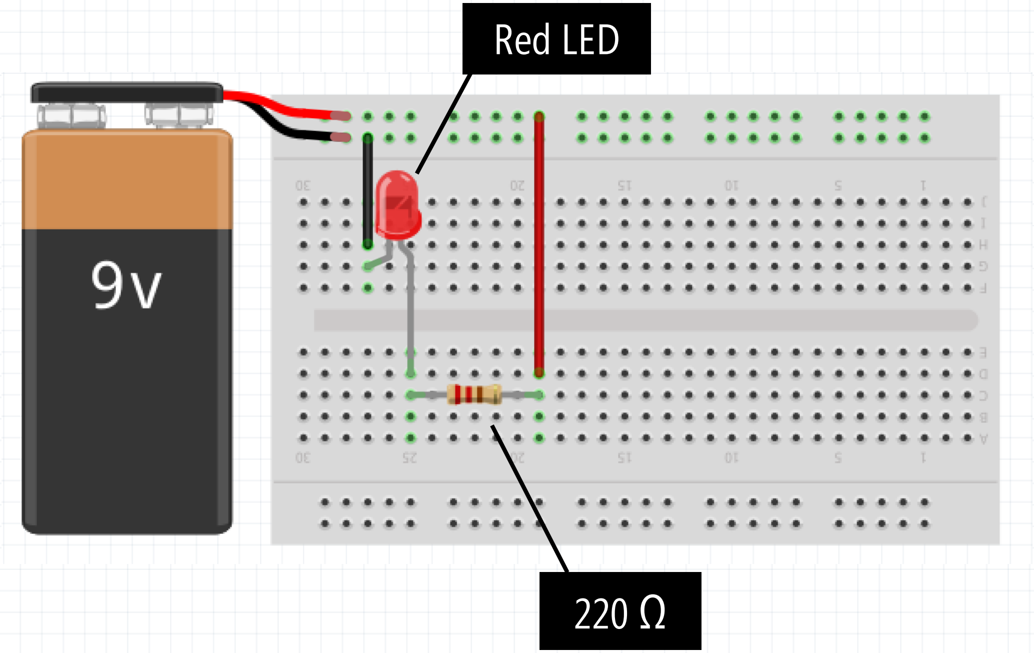


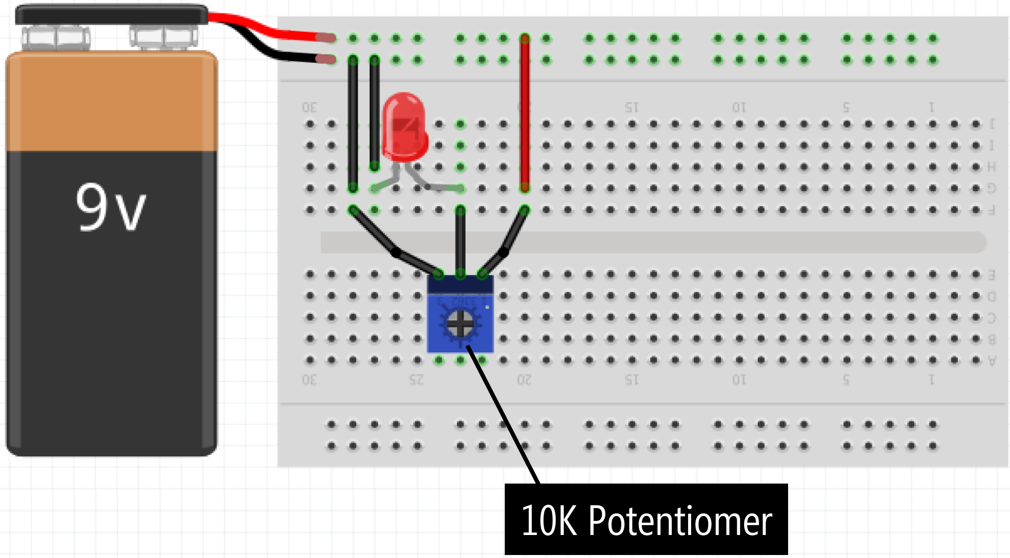

FLUKE
117 TRUE
10.09
kΩ
0 Auto
60
Lo / Hi
HOLD
MIN MAX
RANGE
AUTO-V
OFF
Hz
mV
Ω
Volt

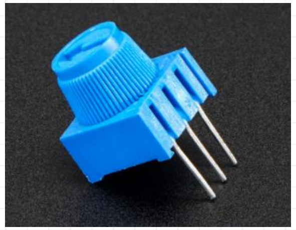
ACTIVITY

SWAP THE FIXED RESISTOR WITH A POTENTIOMETER

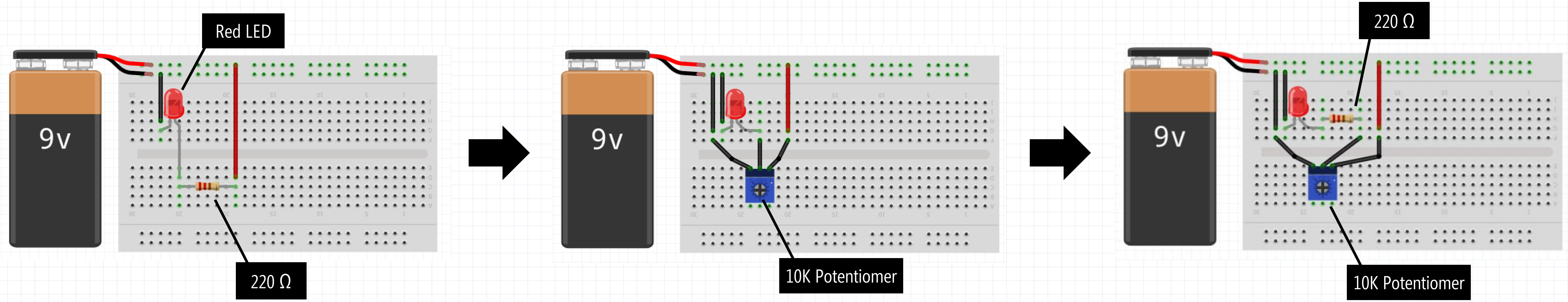
Given the video, who can tell me what's wrong with this circuit?







ACTIVITY
ADD PROTECTION RESISTOR TO POT CIRCUIT

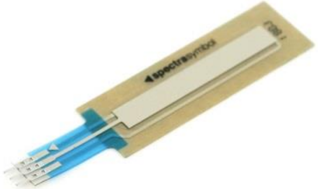


POTENTIOMETER + PROTECTION RESISTOR

The protection resistor ensures that the LED always has a minimum current limiting resistor even when the POT is set to zero ohms (0Ω). If POT= 0Ω, total resistance would be 220Ω.

LOTS OF DIFFERENT KINDS OF VARIABLE RESISTORS

Potentiometer 10k; $0.95*

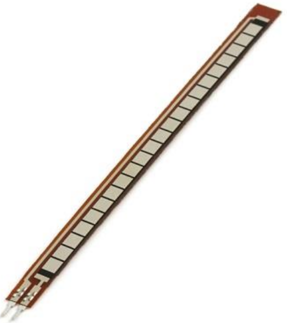


Touch Membrane Potentiometer; $12.95

Photocell (aka photodetector or photo resistor); $1.50

Thermistor 10k; $0.75

Force Resistive Sensor 0.5"; $6.95

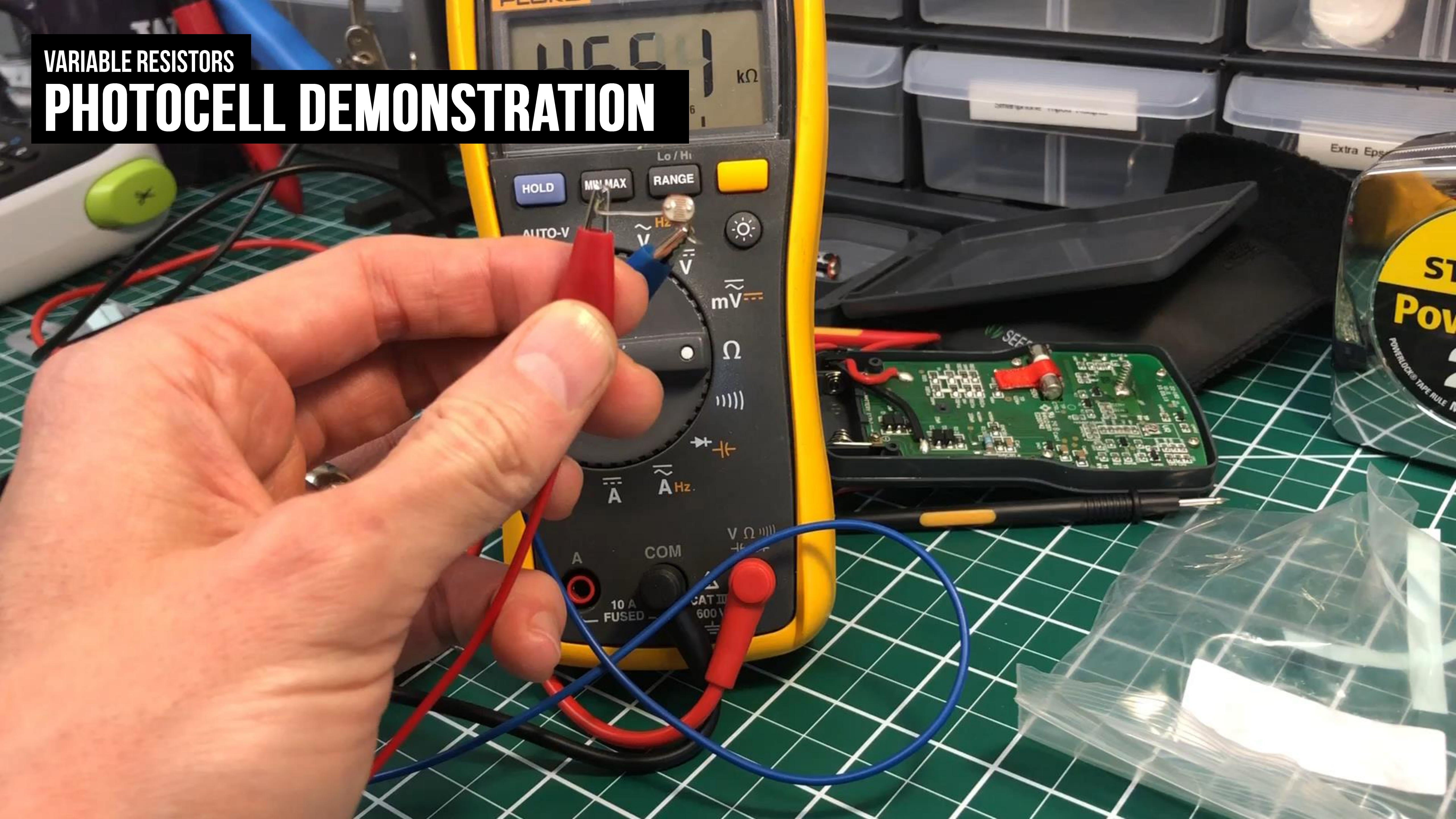


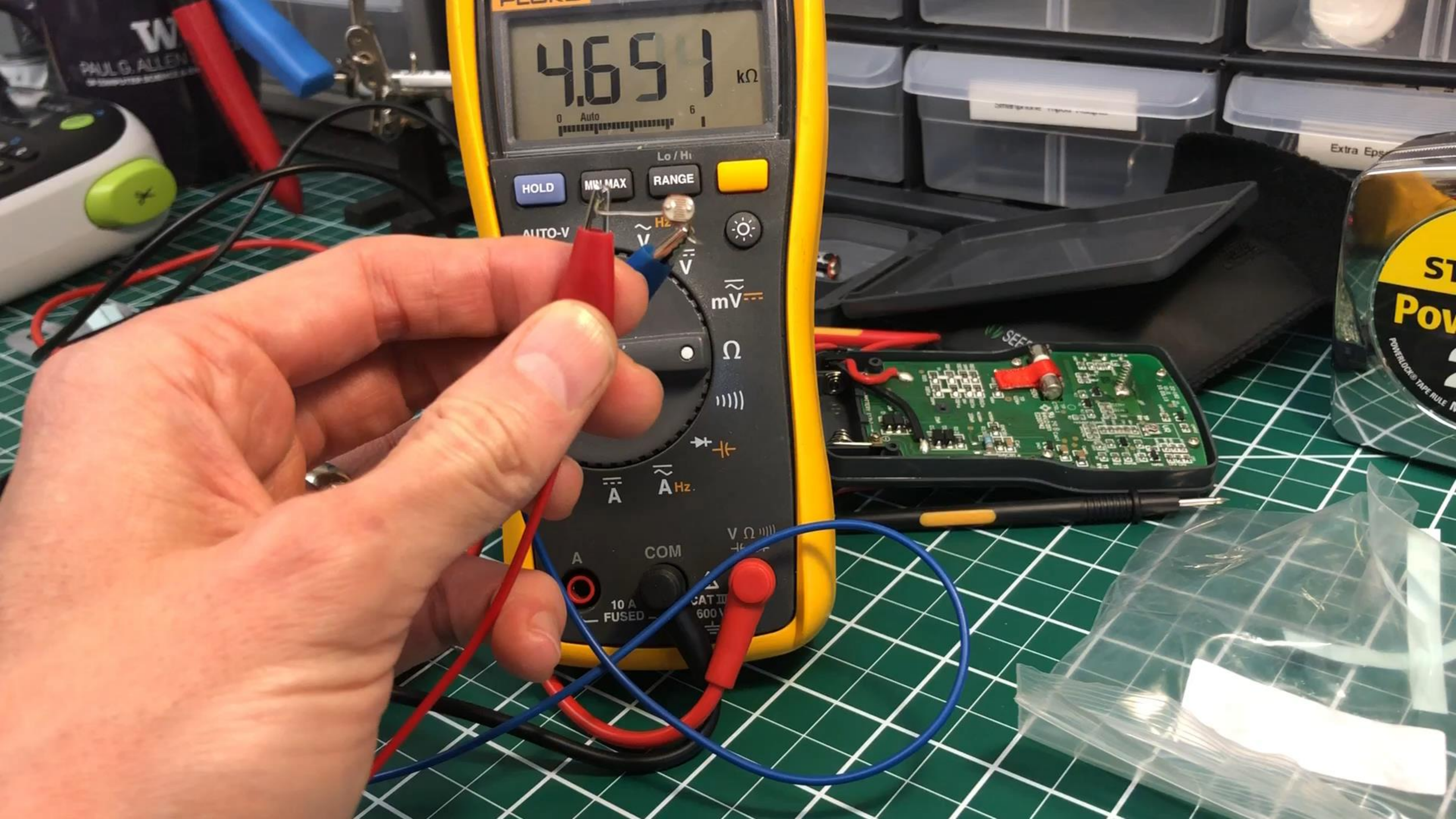
Flex Sensor 4.5"; $12.95

*Note: Prices are from Sparkfun.com; parts are cheaper in bulk and often cheaper from Digikey.com

VARIABLE RESISTORS

PHOTOCELL DEMONSTRATION

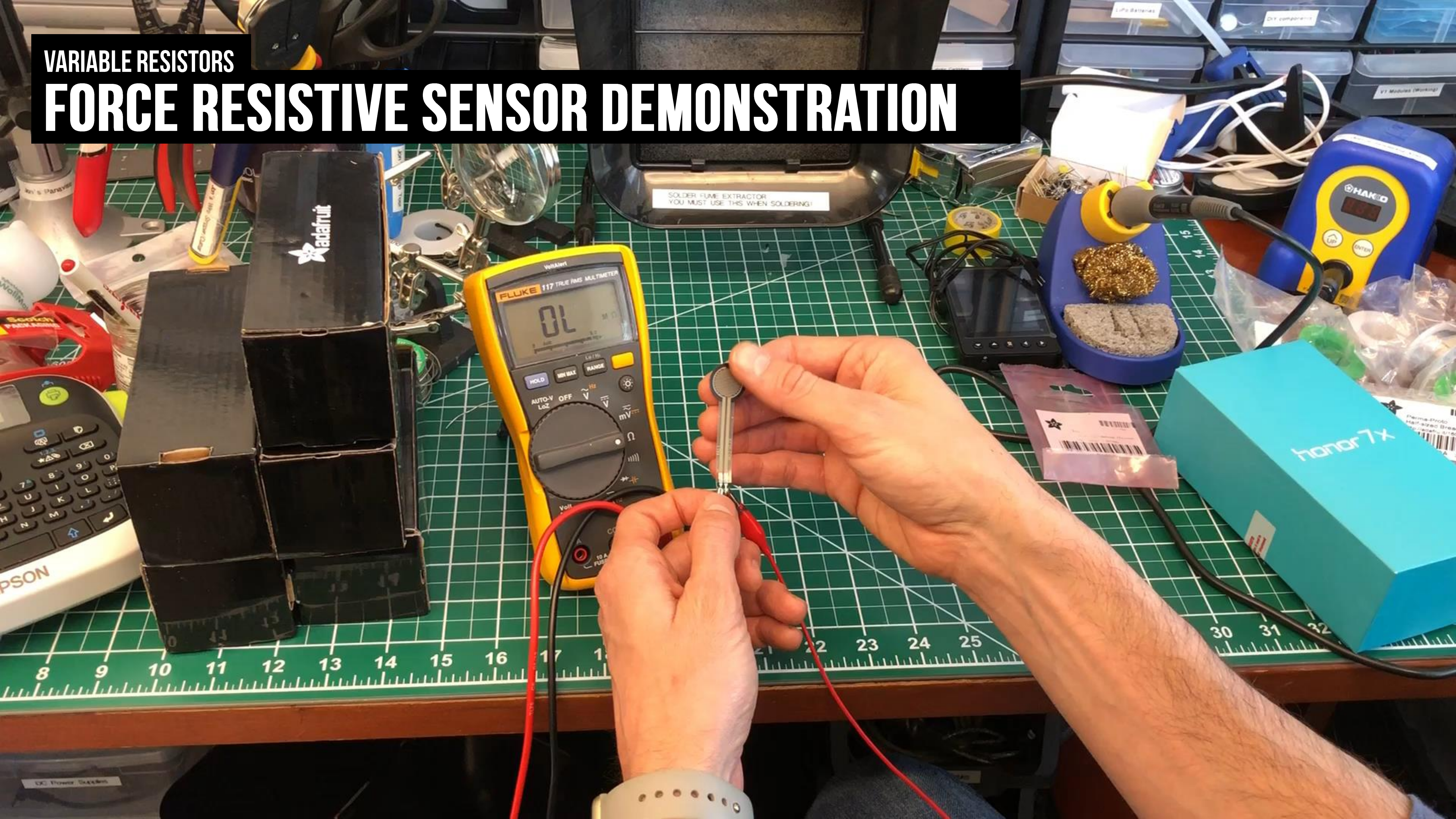


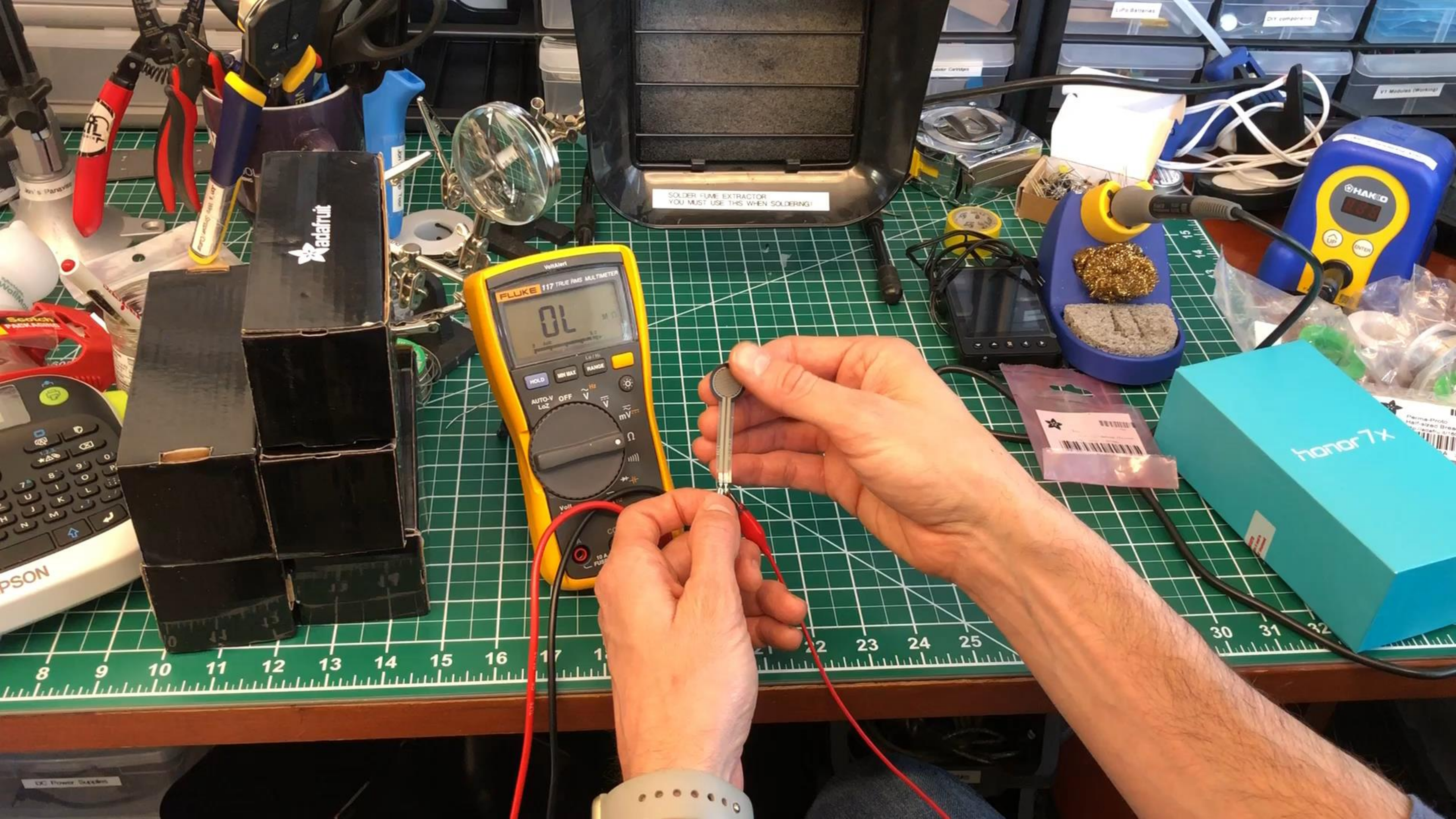


kΩ
0
Auto
6
Lo / Hi
HOLD
MIN MAX
RANGE
AUTO-V
COM
10 A
FUSED
CAT III
600 V

VARIABLE RESISTORS

FORCE RESISTIVE SENSOR DEMONSTRATION





SOLDER FUME EXTRACTOR
YOU MUST USE THIS WHEN SOLDERING!
adafruit
FLUKE 117 TRUE RMS MULTIMETER
0L
HOLD
MIN MAX
RANGE
OFF
HAKKO
honor 7x
EPSON
LiPo Batteries
DIY components
DC Power Supplies

SCHEDULE TODAY: 6:30-9:20

06:30-06:40: Physical Computing Module & Overview of A3 Interactive Night Light

06:40-07:00: Discussion of required reading led by Jordan Raisher

07:00-07:05: Optional discussion led by Gang Chen (link)

07:05-08:00: Intro to basic circuits with exercises

08:00-08:05: Break

08:05-08:20: A2 Debrief. Who wants to share about their project?

08:20-09:20: Intro to Arduino with exercises