PHYSICAL COMPUTING 1: CIRCUITS

CSE 599 Prototyping Interactive Systems | Lecture 2 | April 4

Jon Froehlich • Jasper O'Leary (TA)

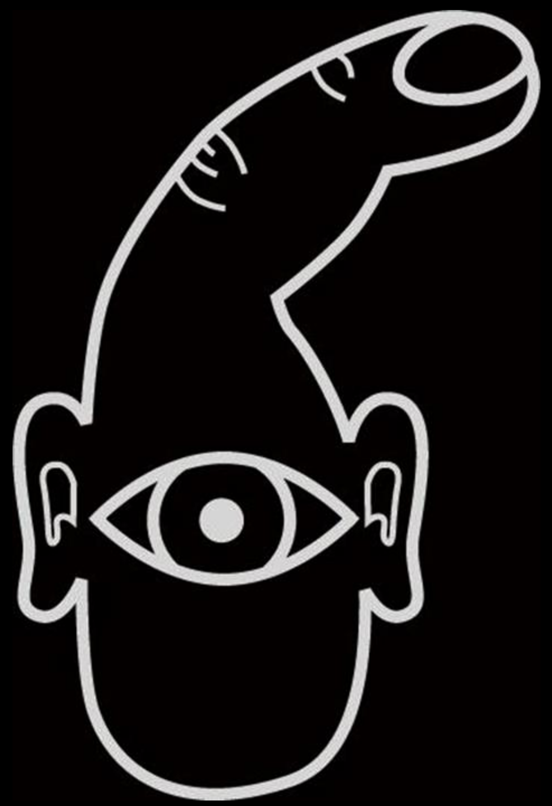
DESIGN USE BUILD

MAKEABILITY LAB

PAUL G. ALLEN SCHOOL OF COMPUTER SCIENCE & ENGINEERING

UNIVERSITY of WASHINGTON

How the computer has traditionally seen us...



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


nest
66
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70


amazon


12:45


Flowers
Plants
Fruits
Food
Animals
Abstracts

OVERARCHING LEARNING OBJECTIVES

In this module, we are going to learn **how to prototype** these rich, **interactive experiences** that **embed computation** in **artifacts**.

We will cover theories, techniques, and tools!

GREAT RESOURCES FOR THIS MODULE

Physical Computing @ ITP/NYU
Online video series
Jeff Feddersen & Tom Igoe, ITP at NYU
Over 100 extremely high-quality teaching videos about circuits, & Arduino

Adafruit's Learn Arduino Series
Online tutorial series
Simon Monk, Author
A nice intro series to key circuit and Arduino concepts.

Sparkfun's Tutorials
Online tutorial series
A nice intro series to key circuit and Arduino concepts.

Exploring Arduino
Book
Jeremy Blum, Author
There are lots of Arduino books and this is one of the best imo

Make: Electronics
Book
Charles Platt, Author
There are lots of introductory books to electronics, this is one of the best

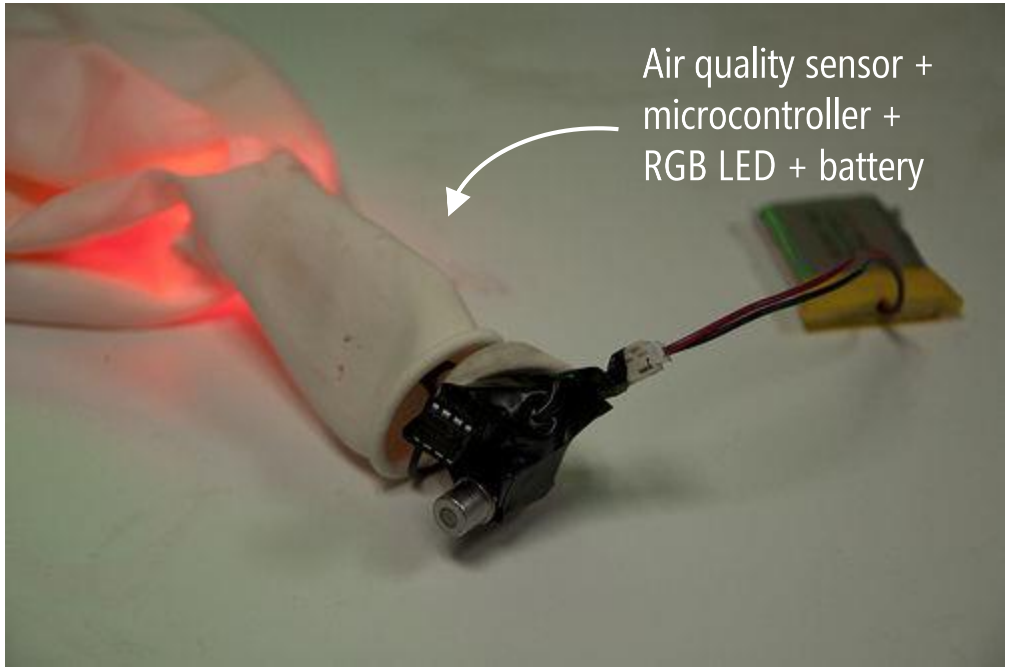
Here are some **example projects** that—by the end of the quarter—you will have the skills to build yourself.

PHYSICAL COMPUTING PROTOTYPE EXAMPLES

AMBIENT AIR POLLUTION SENSORS

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

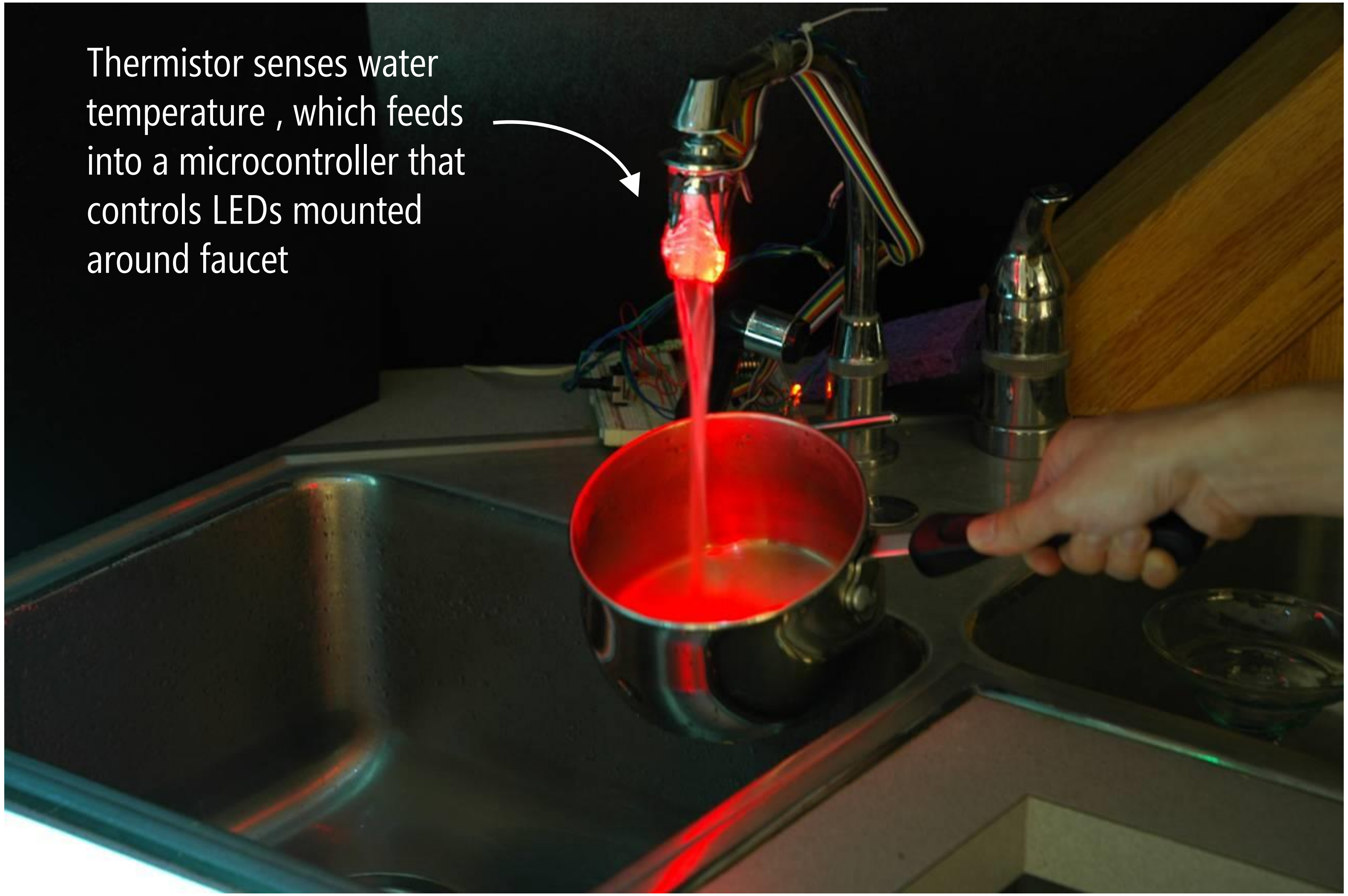

646 593 1745


Air quality sensor +
microcontroller +
RGB LED + battery


Diesel

PHYSICAL COMPUTING PROTOTYPE EXAMPLES

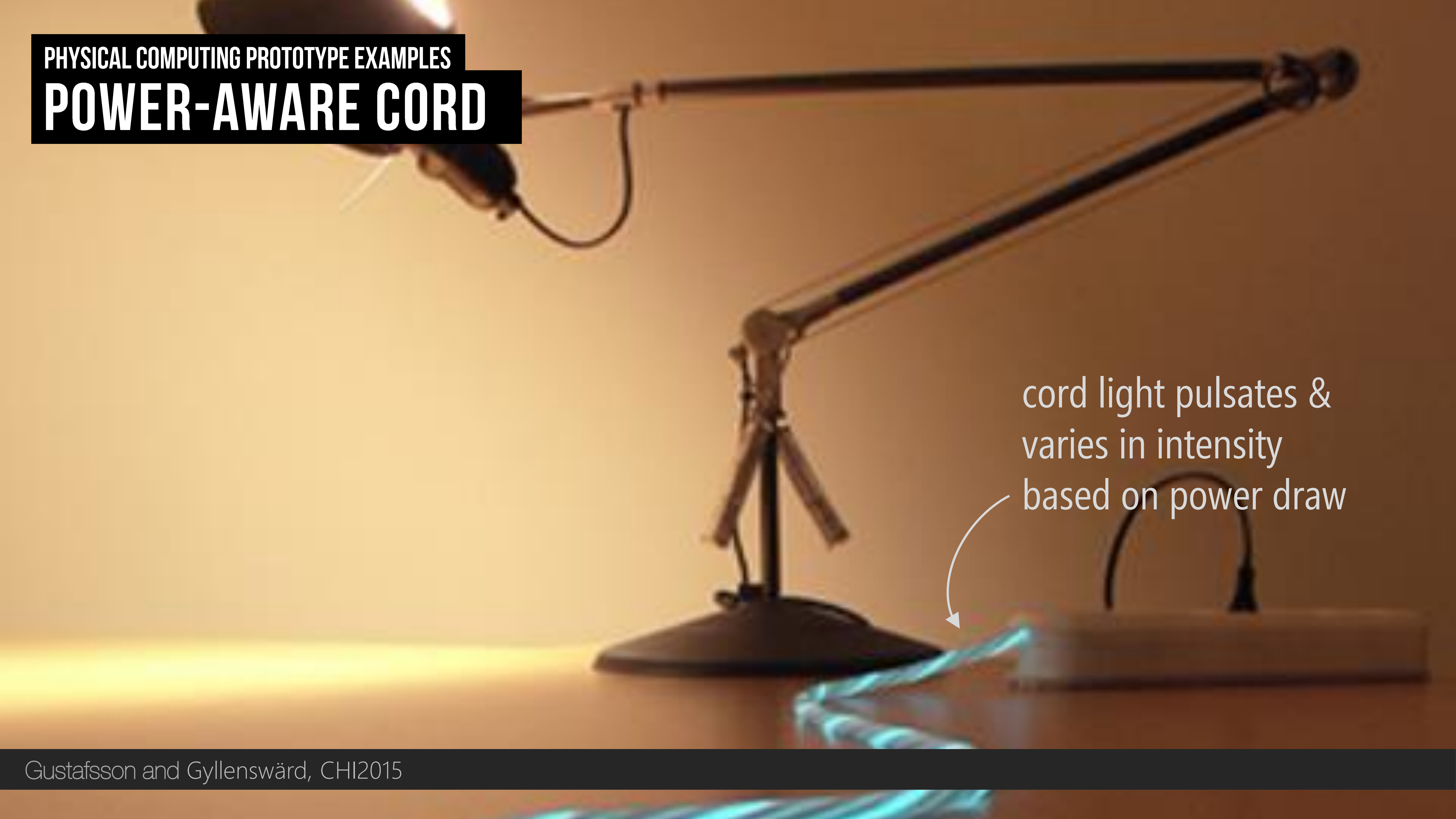
HEATSINK



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

PHYSICAL COMPUTING PROTOTYPE EXAMPLES

POWER-AWARE CORD



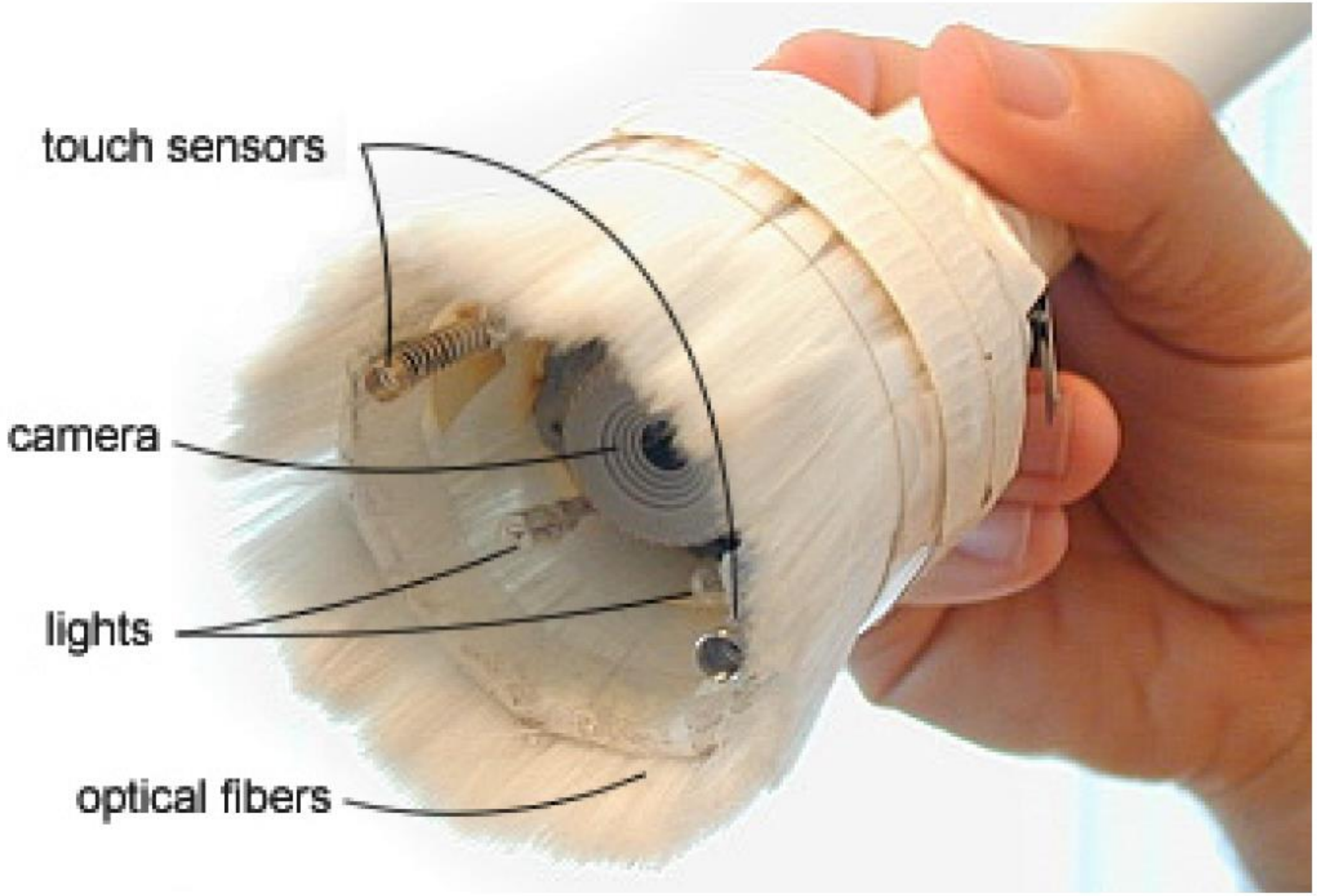
Gustafsson and Gyllenswärd, CHI2015

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/]

ASSIGNMENT

A1: INTERACTIVE NIGHT LIGHT

[2 pts] **Interactive RGB circuit.** Design your light using an RGB LED. The individual color hues should be selectable via custom physical controls that you design (see next bullet). The brightness of the LED should change automatically based on ambient light (inversely proportional to light level).

[2 pts] **Lo-fi input.** Use craft materials (*e.g.,* clay, conductive paint, paper) to build a DIY input sensor

[1 pt] **Lo-fi enclosure.** Create a lo-fi form (e.g., using cardboard, paper, foamcore, etc.) that fully encloses hardware

[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), or a way of presenting ambient information

[2 pts] **Deliverables**. Including source code, slide deck report, and short video demo. We will also have live demonstrations in class on April 18th.

A1 EXAMPLES

TINY CLOUD

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

A1 EXAMPLES

INTERACTIVE WALL HANGING

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


蒲公英圖

EXAMPLES

MECHANICAL TULIP

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


THE LOST WORLD
ARTHUR CONAN DOYLE

Ever Blooming Mechanical Tulip

Mechanical tulip sculpture that blooms with just gentle touch and can shine into any color of a rainbow.

AUTHOR

Jiří Praus

3 PROJECTS 59 FOLLOWERS

PUBLISHED ON

February 19, 2019

TODAY'S LEARNING GOALS

What is a **circuit, voltage, current, and resistance**

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

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

What is **Ohm's Law** and why is it useful?

Series vs. **parallel** resistive circuit configurations

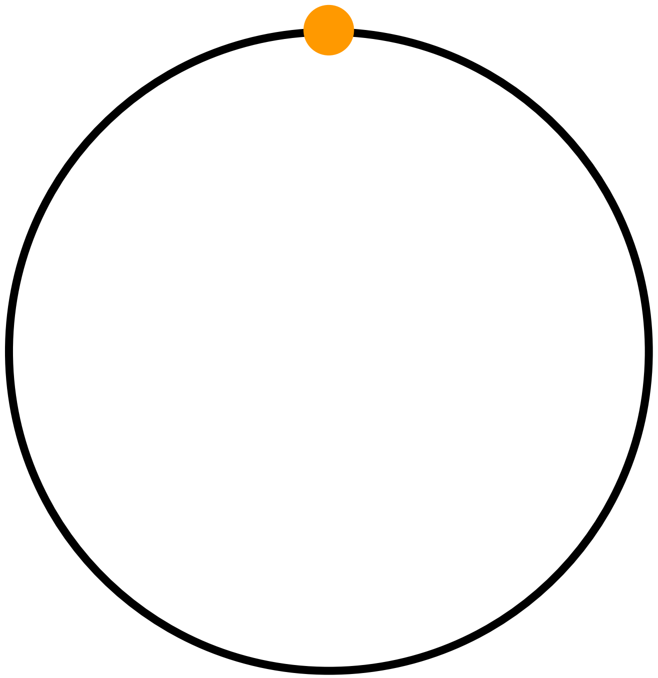
What is a **breadboard** and how to use it

How to **read a datasheet**

ARE YOU READY?!

WHAT IS A CIRCUIT?

WHAT IS A CIRCUIT?



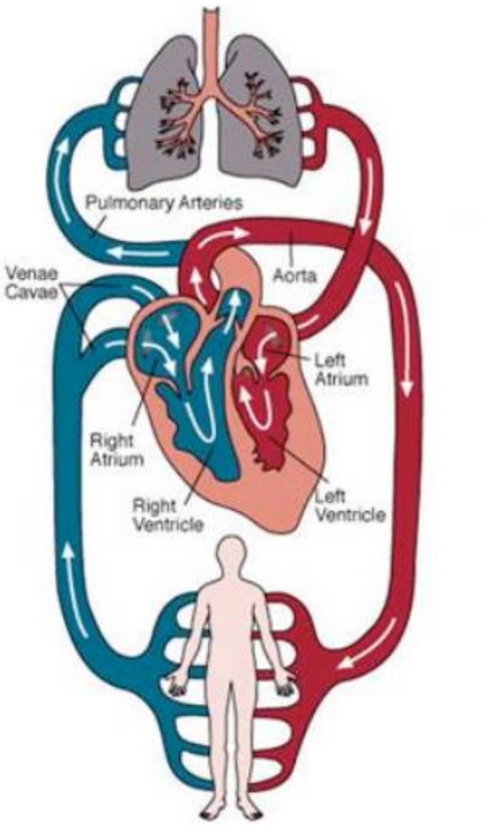
cir·cut [noun]

A route that starts and finishes at the same place.

- Oxford Dictionary

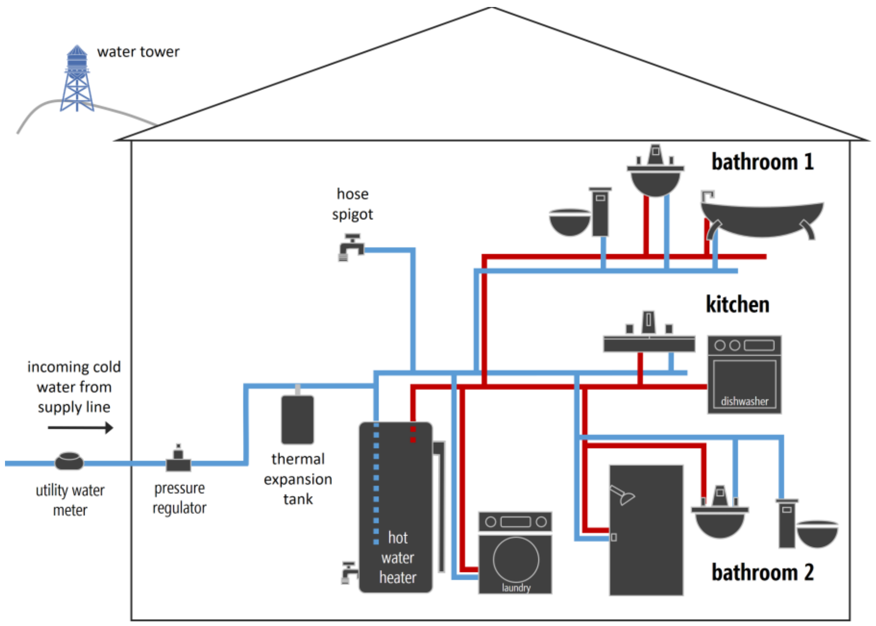
SOME EXAMPLE CIRCUITS

HUMAN CIRCULATORY SYSTEM



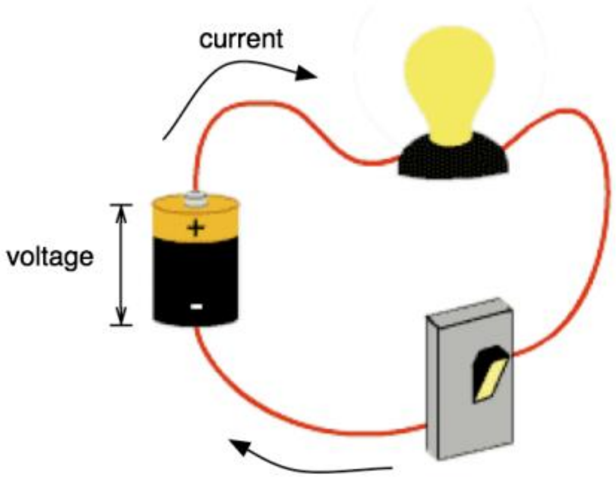
Heart pumps, blood flows

WATER PLUMBING SYSTEM



Water pressure pushes, water flows

ELECTRICAL CIRCUITS

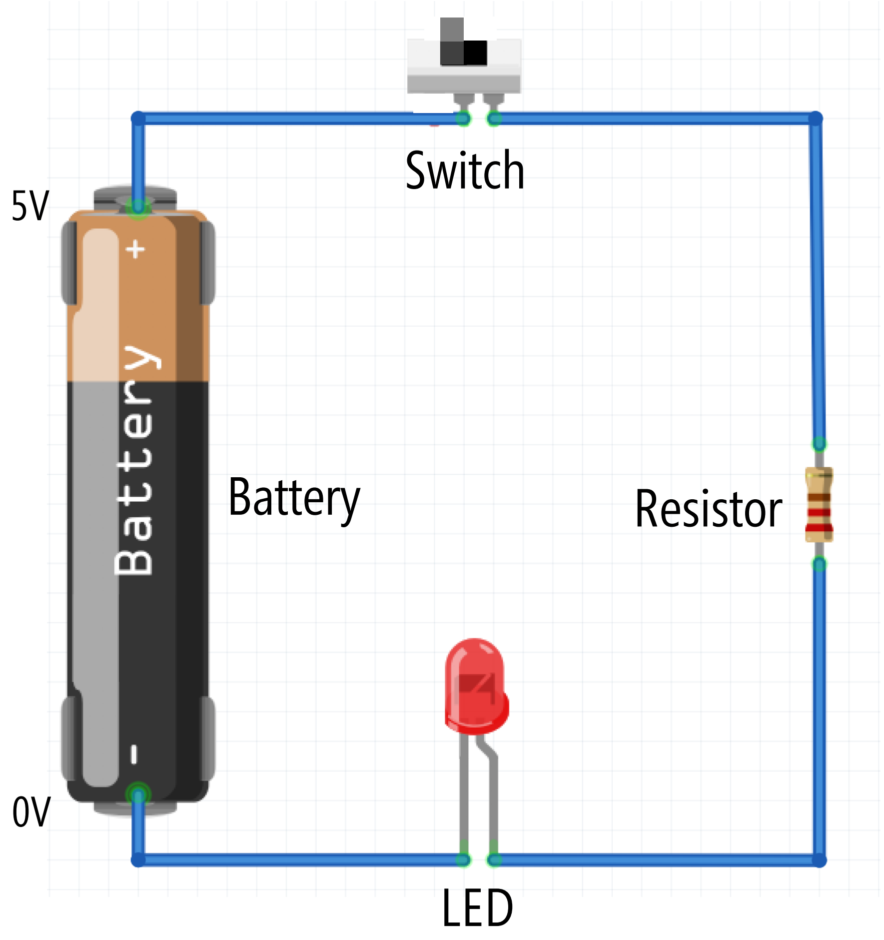


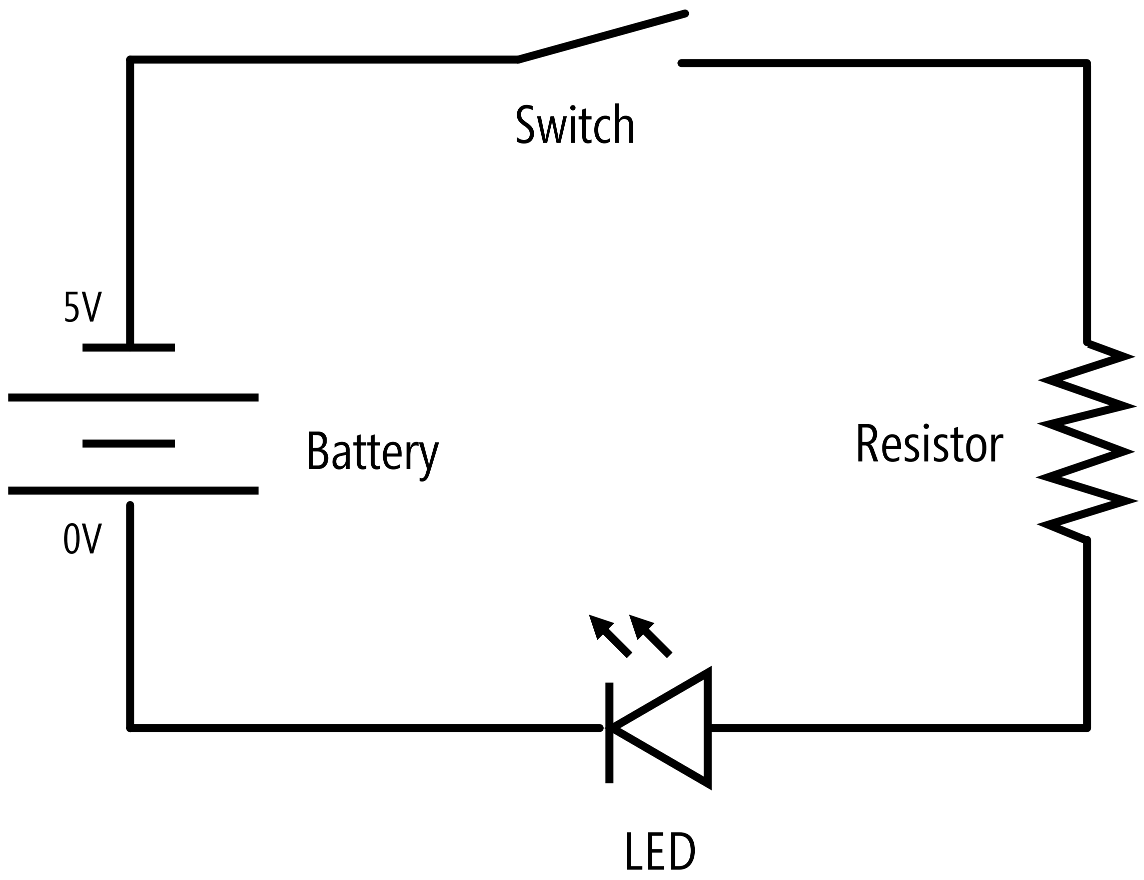
Voltage pushes, current flows

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

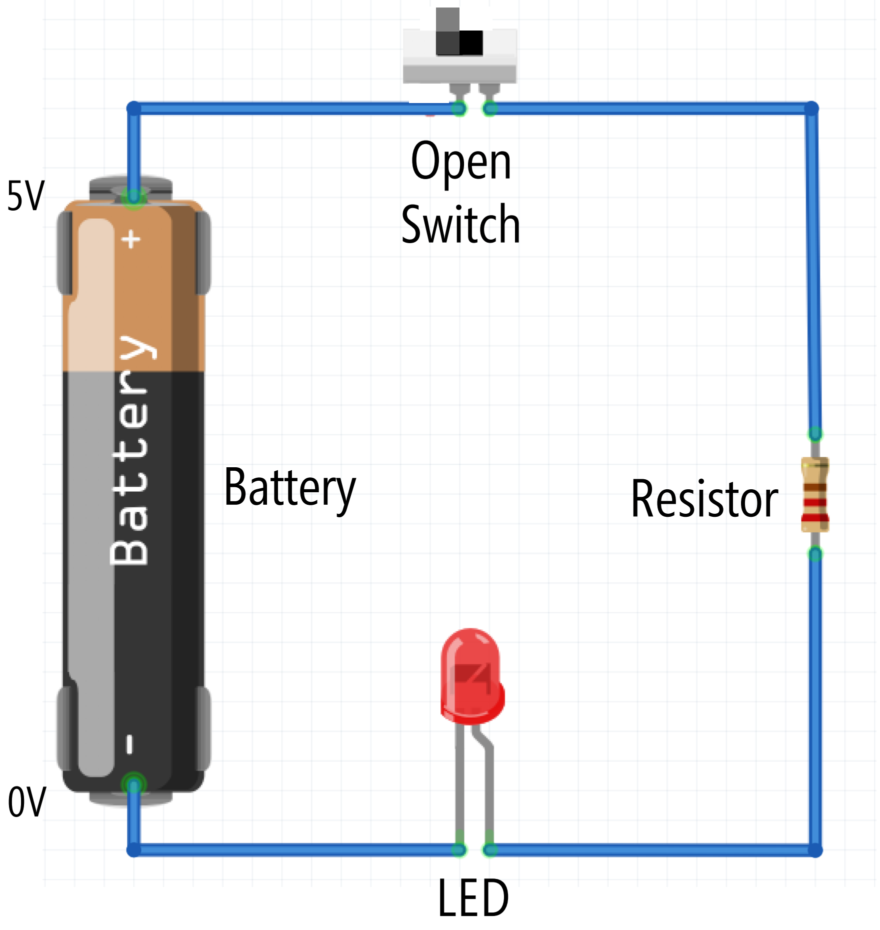
CIRCUITS

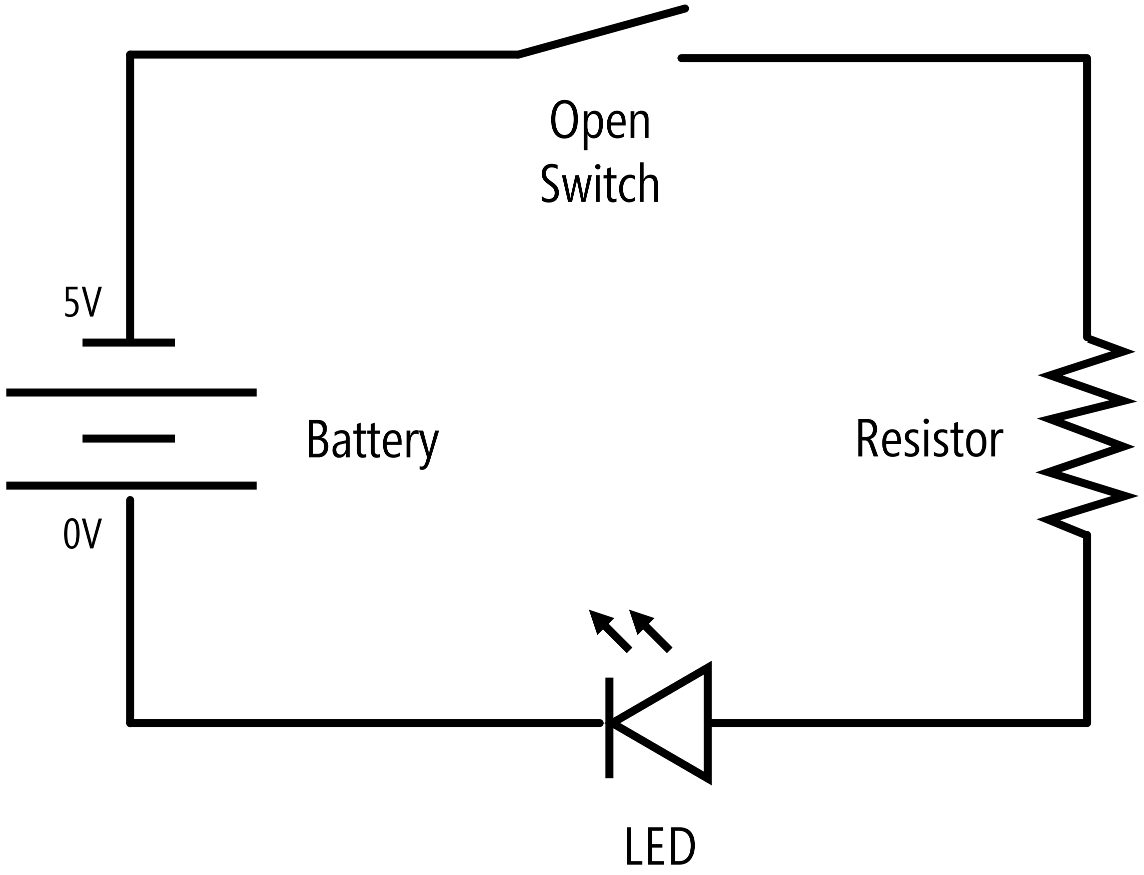
PICTORIAL VS. SCHEMATIC CIRCUIT DIAGRAMS



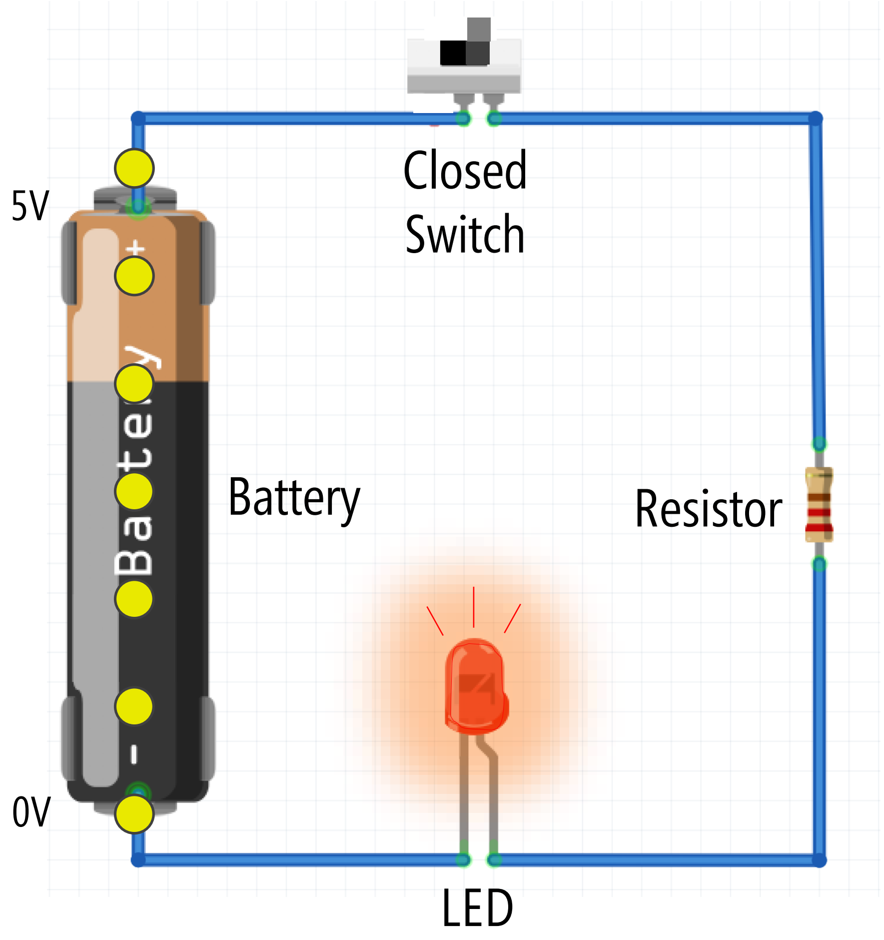


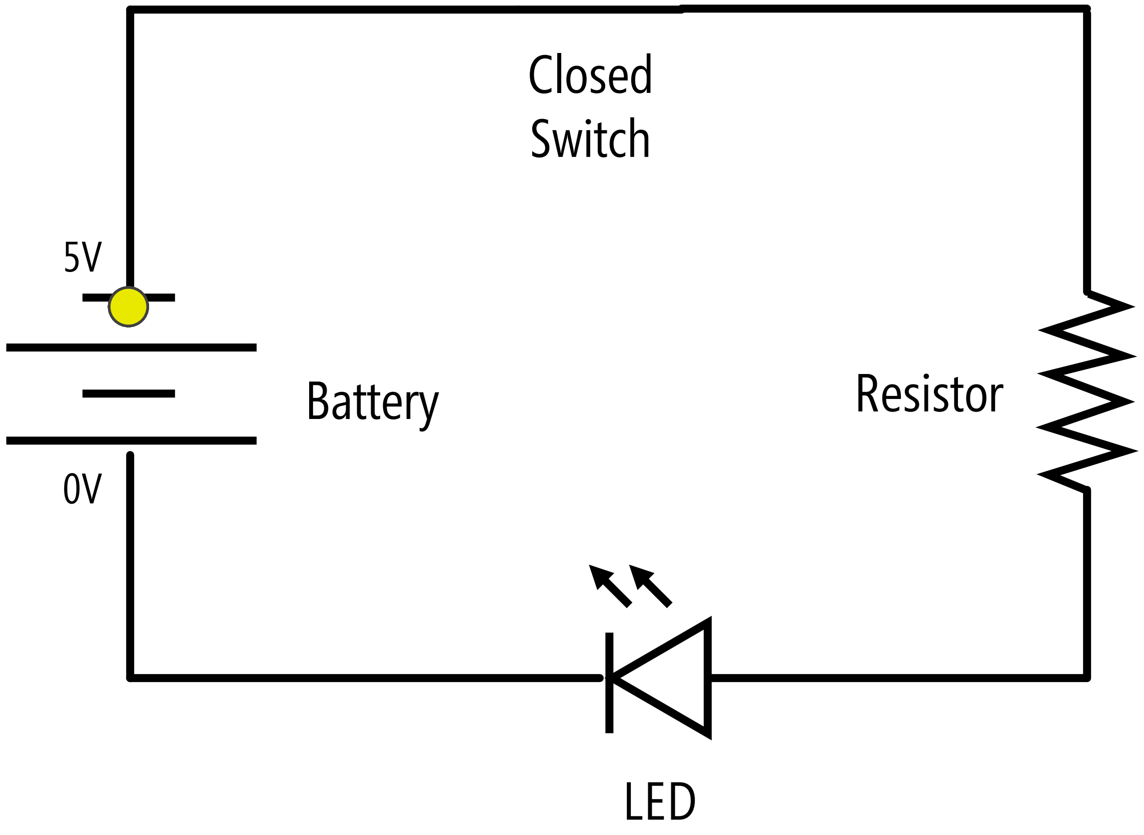
OPEN CIRCUIT: NO CURRENT FLOWING



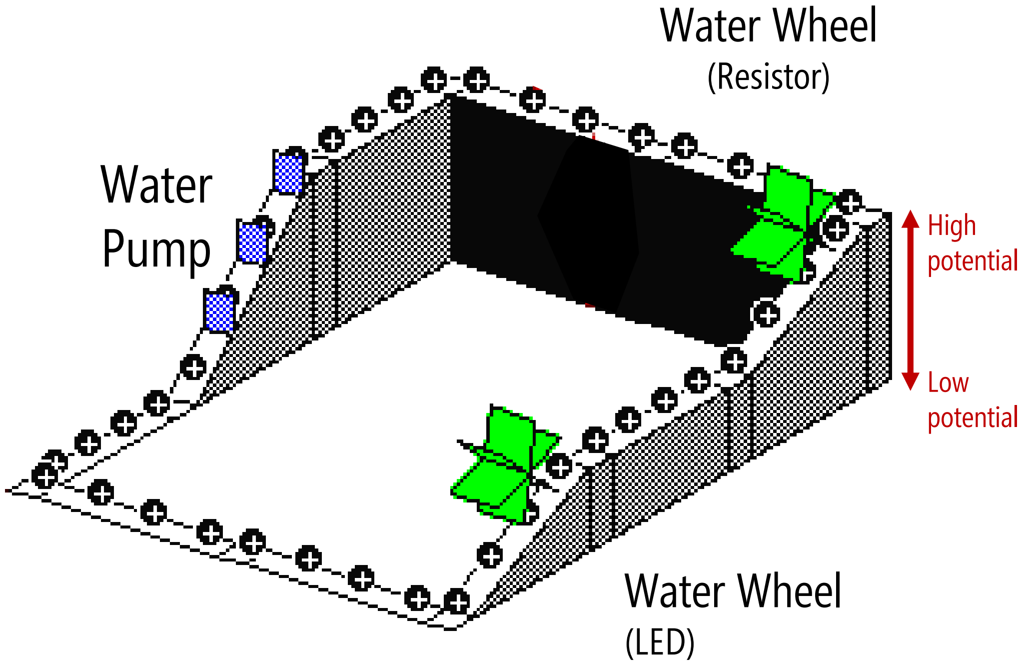


CLOSED CIRCUIT: CURRENT FLOWING





ELECTRIC CIRCUITS: WATER ANALOGY



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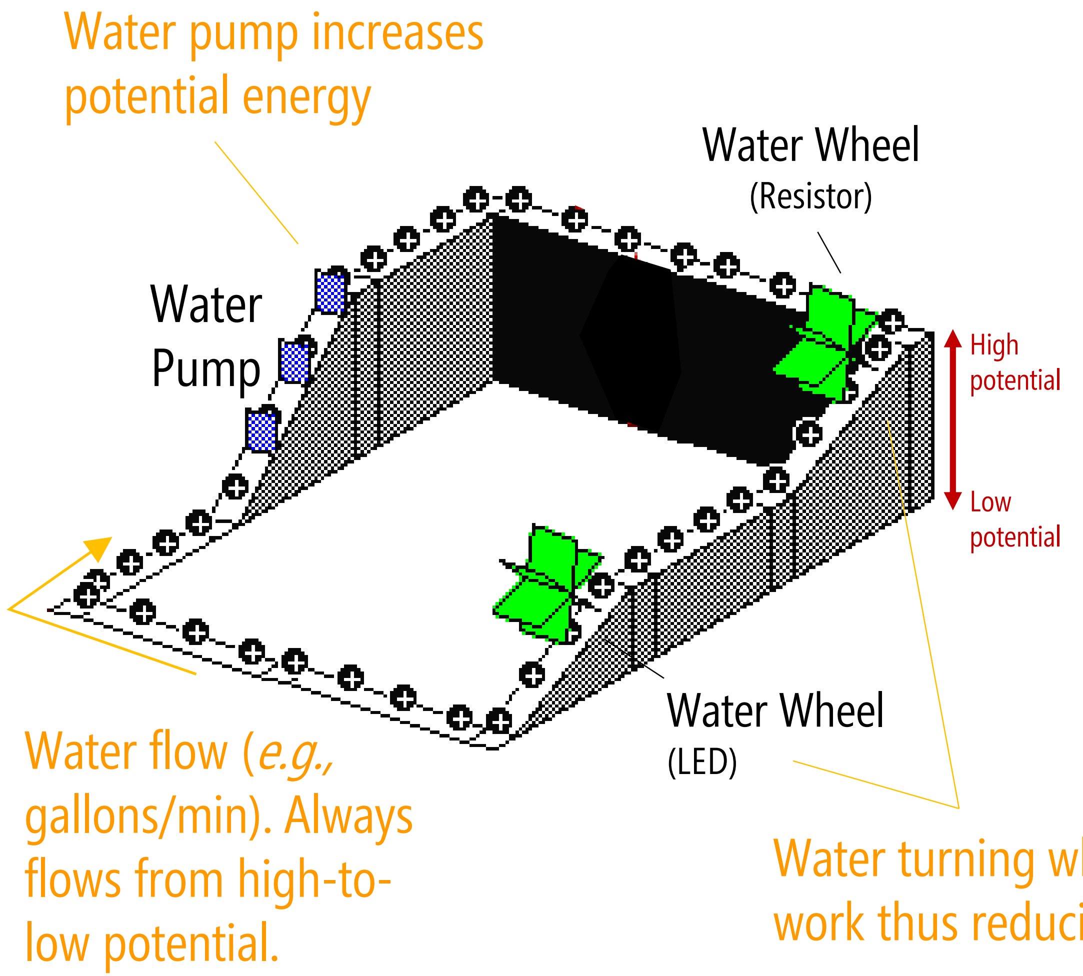
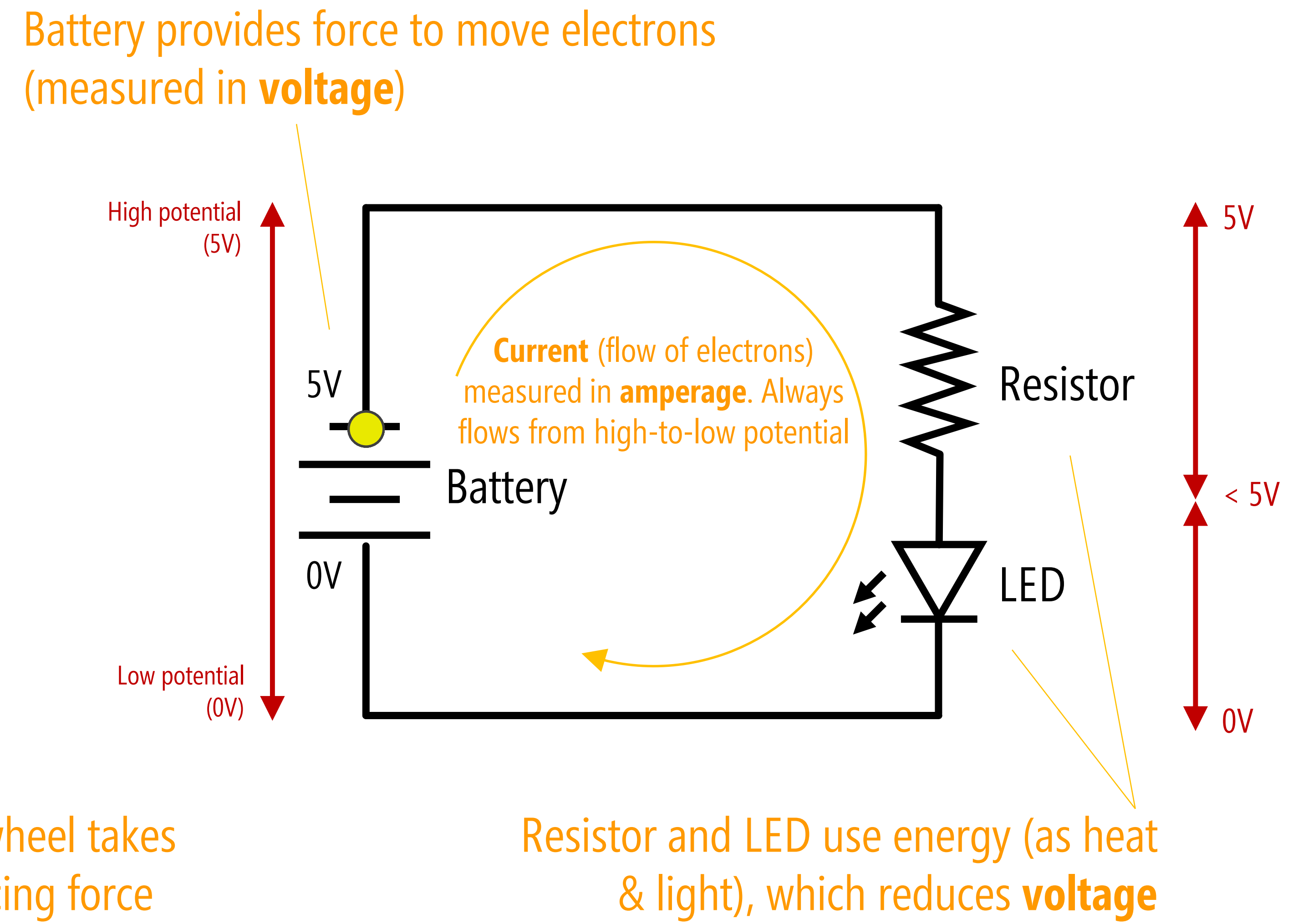
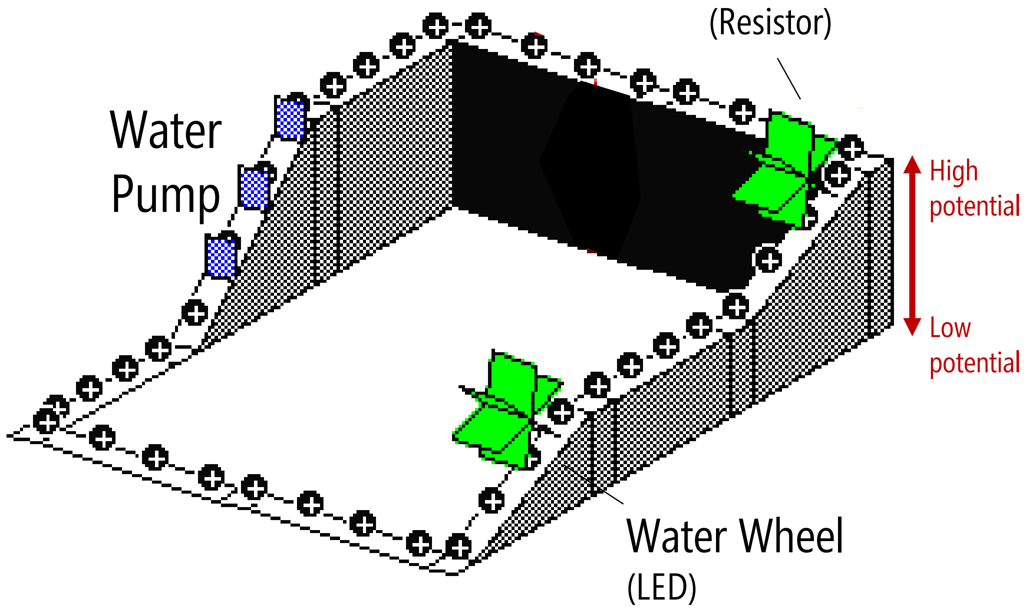
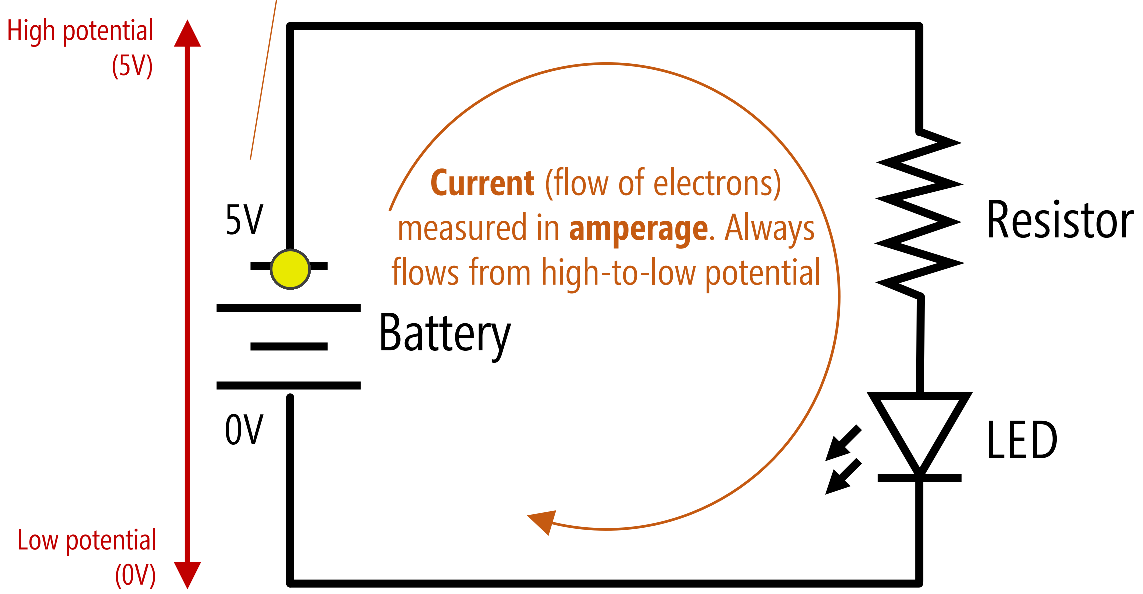








wa·ter pres·sure [wä-dər ˈpre-SHər] | measured in *pounds per square inch (psi)*

Pressure pushes water molecules from high pressure to low pressure. Gravity (or other external forces) can also move water from high potential to low potential.

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

Voltage pushes electrons in a circuit using an electromotive force (EMF) from high potential to low potential.

flow [flō] | measured in *gallons/second (or liters/second)*

Flow is a measurement of the amount of water through a medium over time. Current always flows from highest potential to lowest.

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

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

pipe size [pīp sīz] | measured in *inches* or *meters*

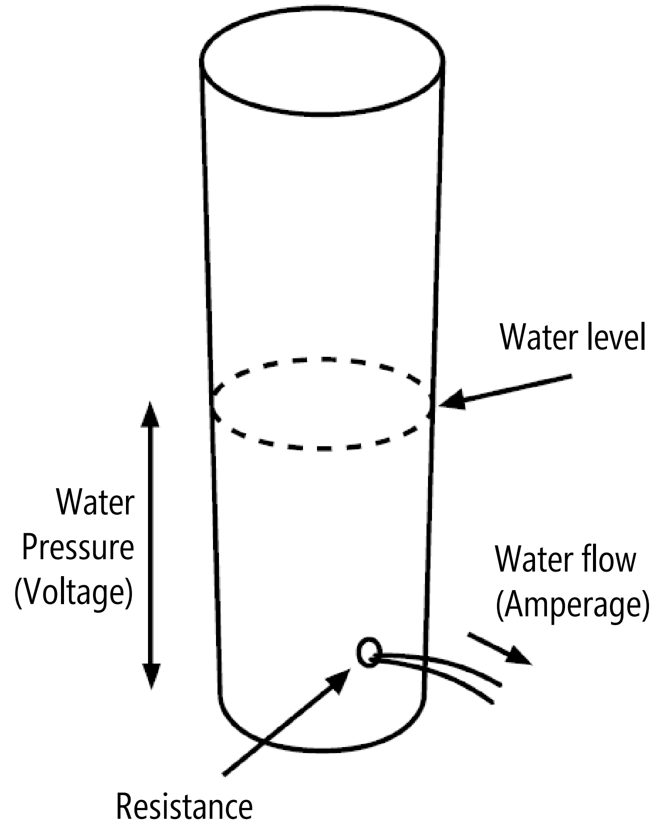
Water flow directly corresponds to pipe size. The larger the pipe, the more flow.

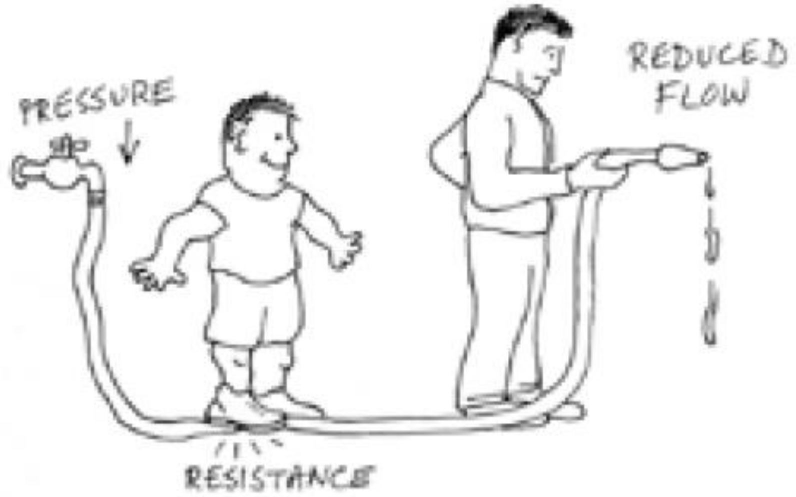
re·sist·ance [ri-**zis**-*tuhns*] | measured in *ohms (Ω)*

A material's tendency to resist the flow of charge (current). The higher the resistance, the less current.

Simplified from: Scherz & Monk, Practical Electronics for Inventors, 3rd Edition and http://arduinotogo.com/2016/10/07/chapter-4-electricity-an-overview/

ELECTRIC CIRCUITS: WATER ANALOGY 2

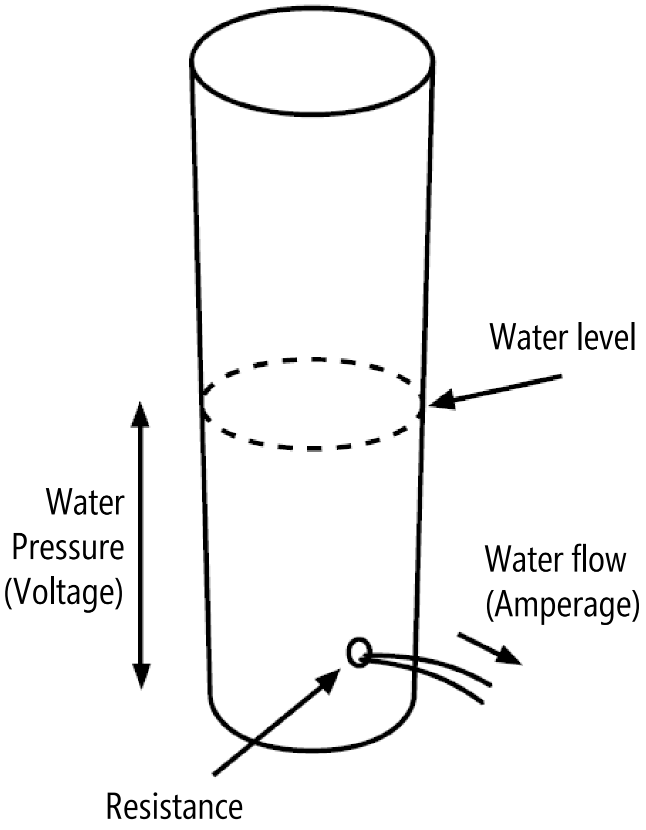


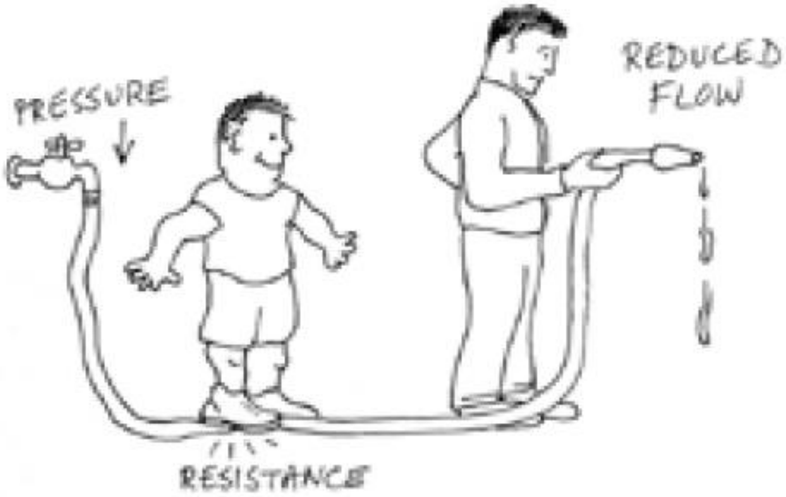


Increase resistance, reduce flow

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

ELECTRIC CIRCUITS: WATER ANALOGY 2





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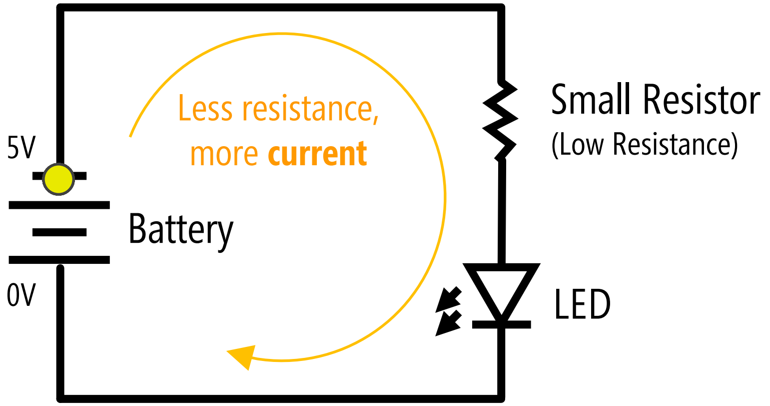
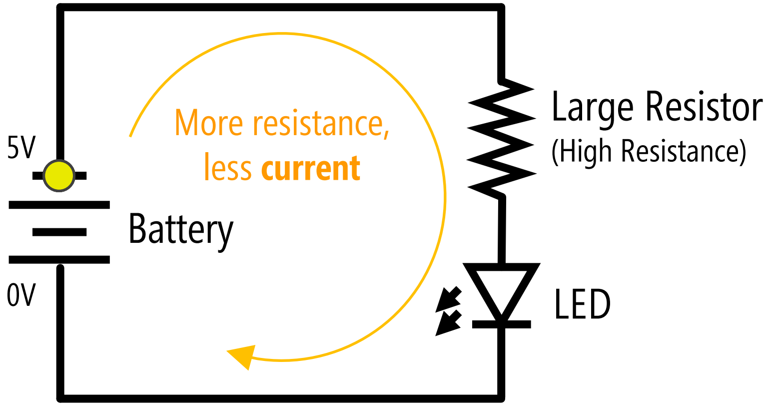
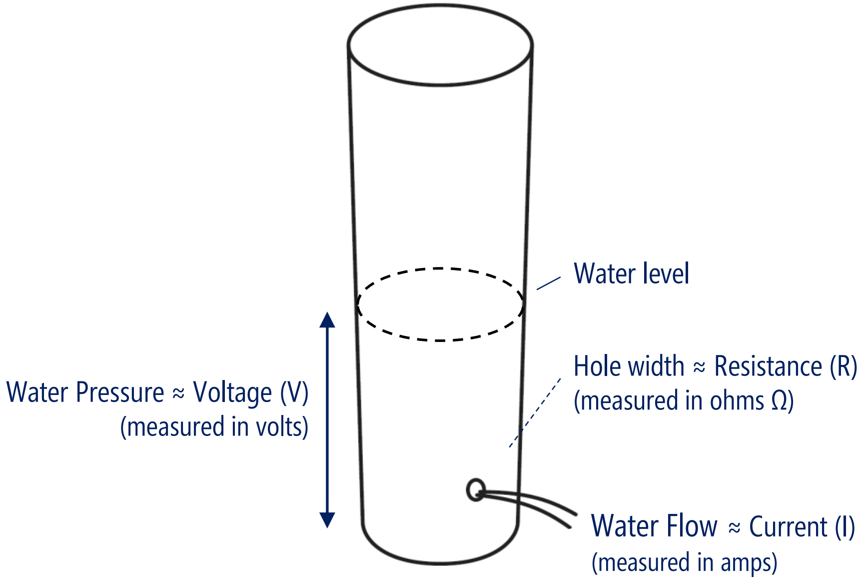
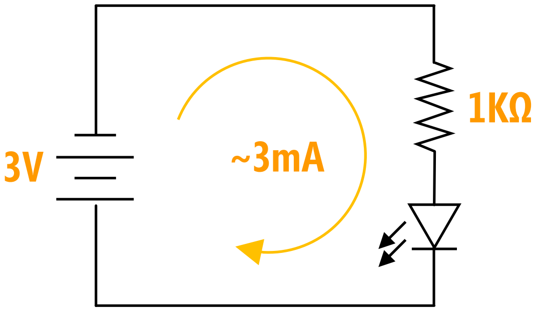




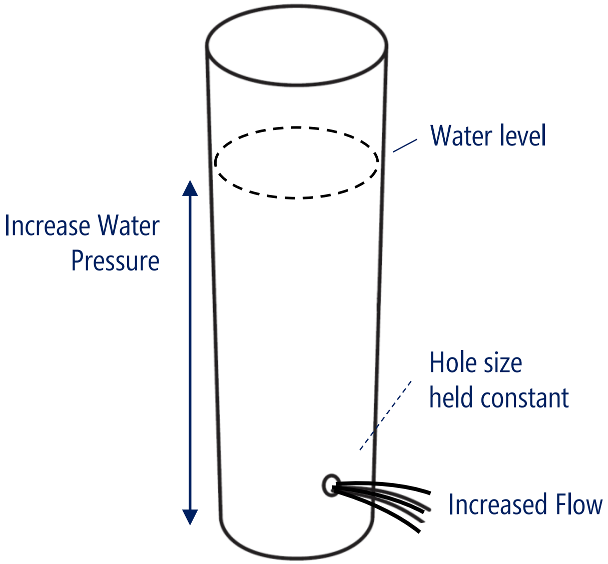
TWO WAYS TO INCREASE CURRENT

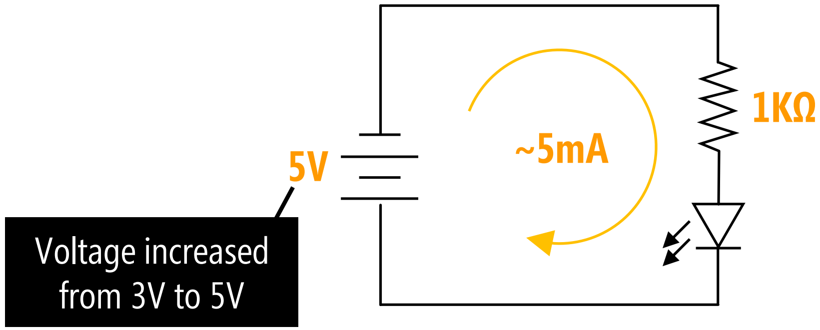
Base Circuit



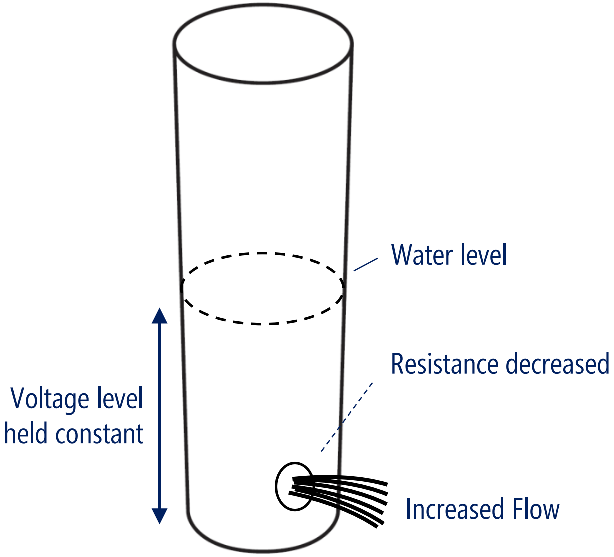


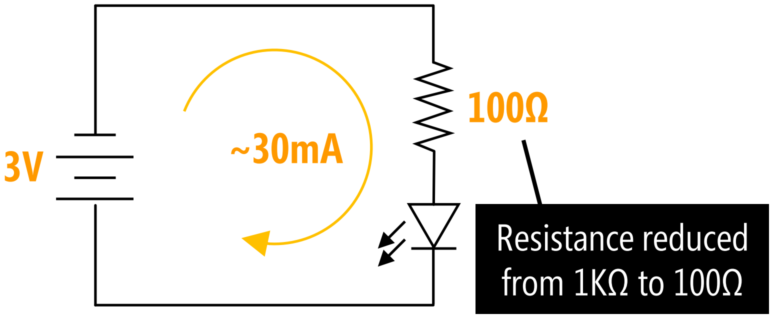
Increase Voltage





Decrease Resistance

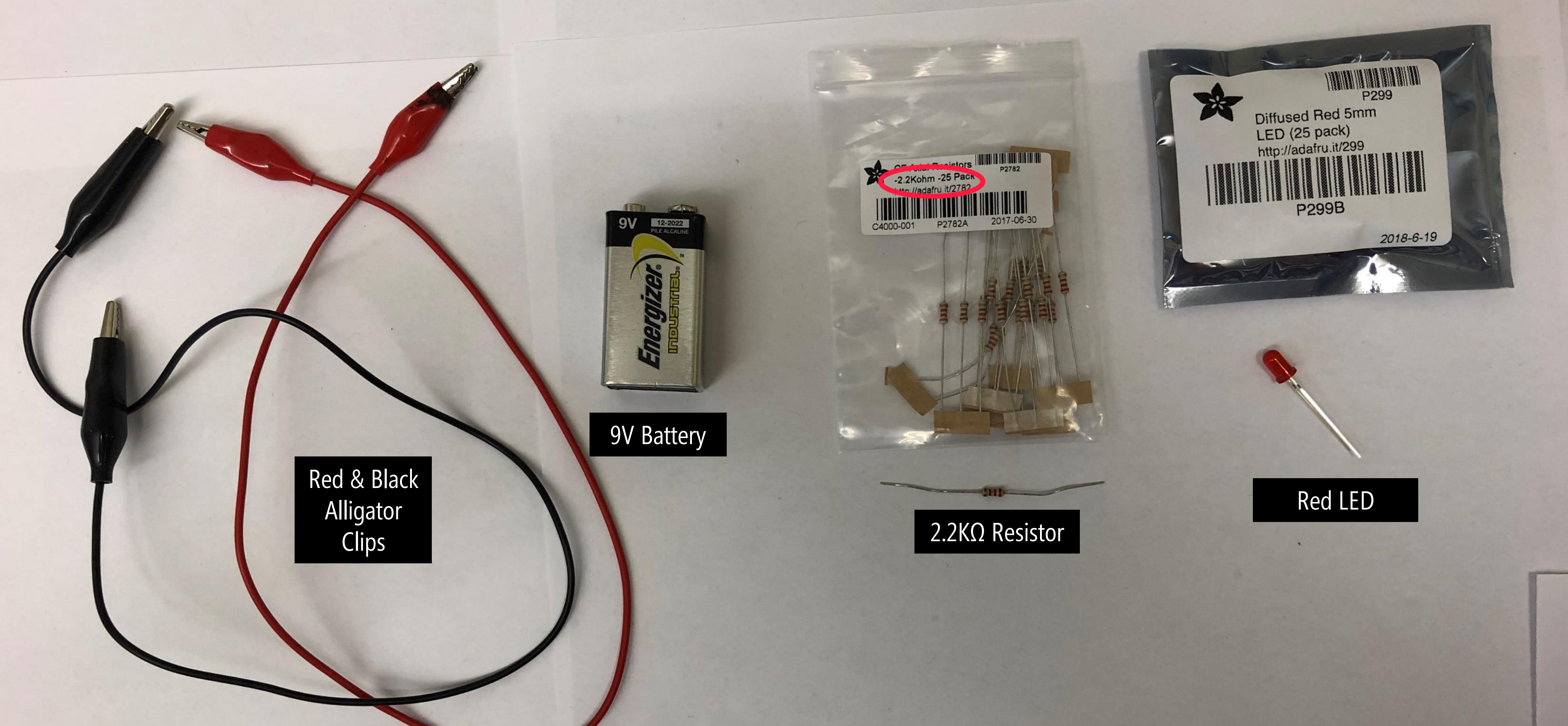




Based on figures from: Platt, Make: Electronics, 1st Edition

ACTIVITY

BUILD YOUR FIRST CIRCUIT: RESISTOR + LED



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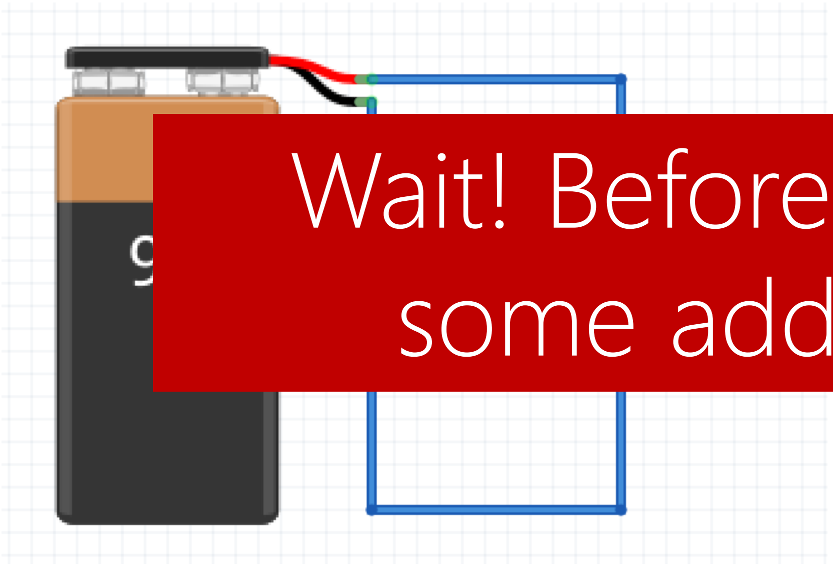
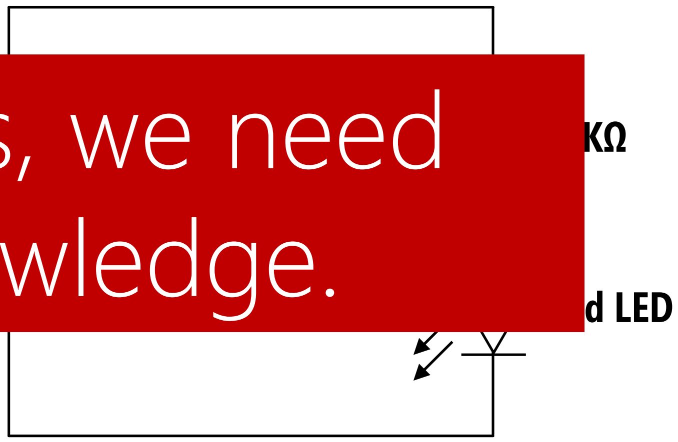


DIAGRAM VIEW



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 current (amperage)** is what can kill you or cause tissue damage. To get high amperage, you need high voltage and low resistance.

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 useful to have some idea of typical current draws when working with electronics.

Microwave

Low-Power Microchip

Toaster

SmartPhone

Typical LED

100W lightbulb

Laptop

Lightening Strike

What do you think draws the **most current**?

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

CURRENTS IN PERSPECTIVE

It's useful 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]

DANGEROUS CURRENT LEVELS

DC Current	Probable effect on human body
1 - 5 mA	Tingling sensation
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20 - 100 mA	Paralysis, heart stoppage

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."

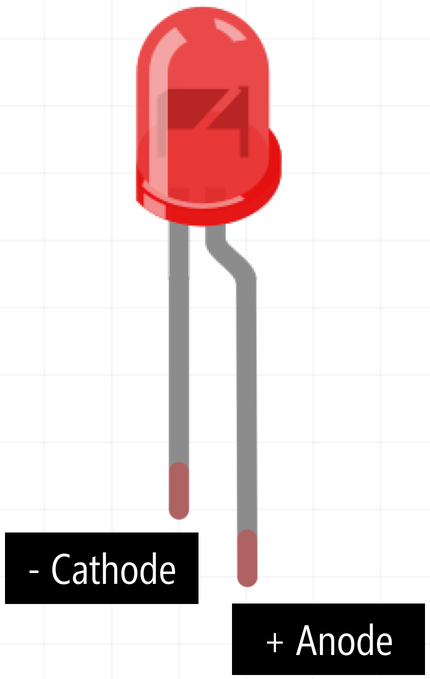
We'll be (mostly) working with **3.3V** and **5V DC**. Imagine your skin has ~50KΩ resistance, with 5V, that's **0.0001 amps** or **0.1 mA**, which is well within the safe range. Whew!

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

LEDS AND HOW TO USE THEM

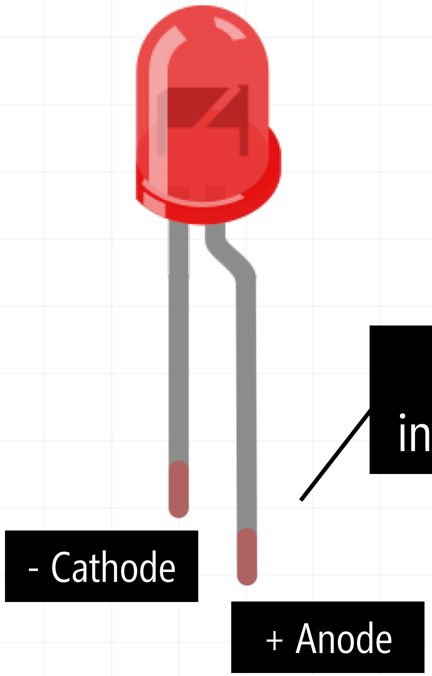
WHAT IS A LIGHT-EMITTING DIODE (LED)?

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



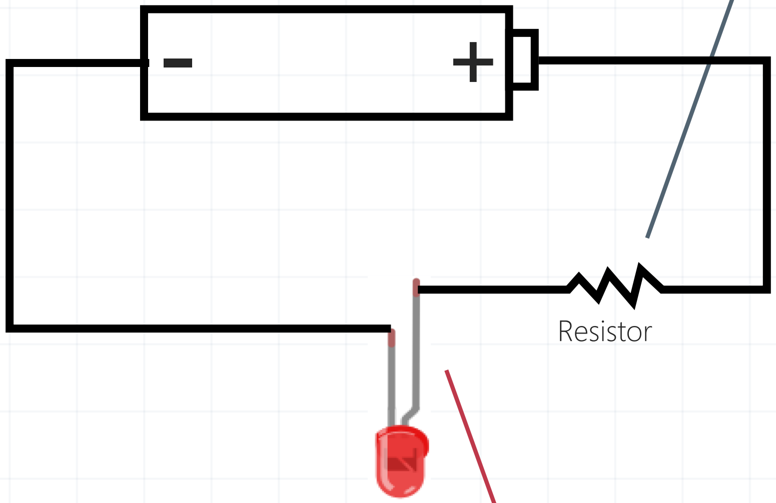
USING LEDS

LIGHT-EMITTING DIODES (LEDS)



The “long leg” indicates the anode.

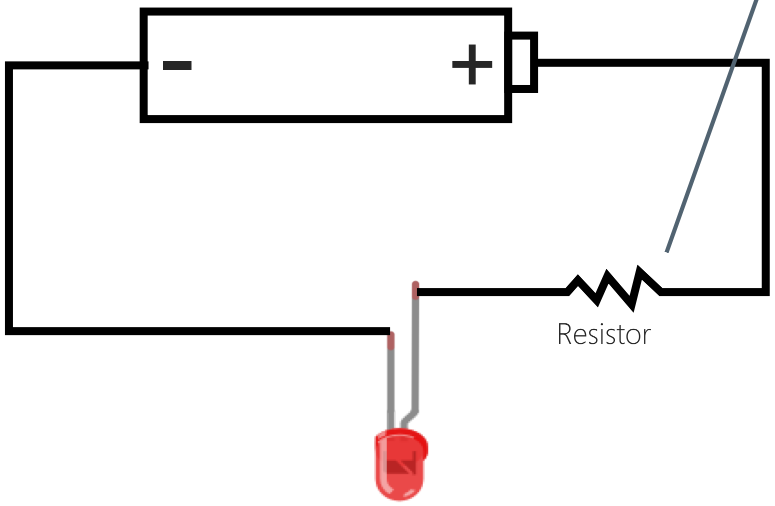
LEDs require **current limiting resistors**. Do not hook up an LED directly to a power source without a resistor or the LED could burn out.

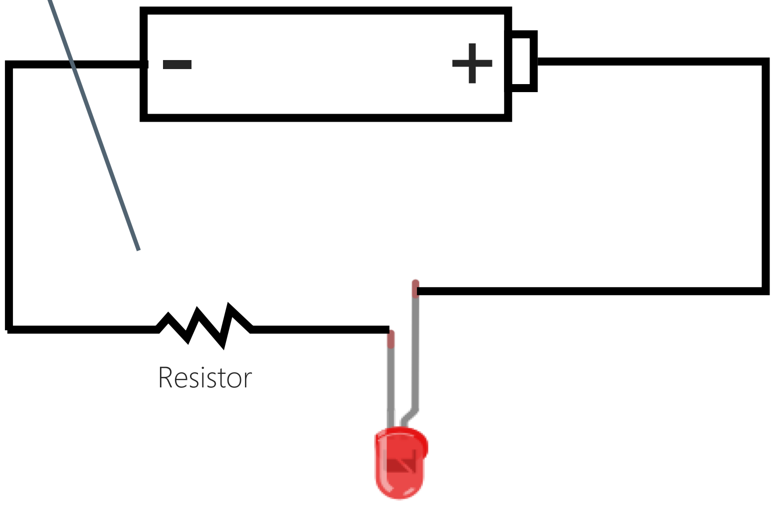


Unlike resistors, LEDs have **polarity**. They only allow current to flow in one direction. The long leg (the anode) must be connected towards positive supply voltage.

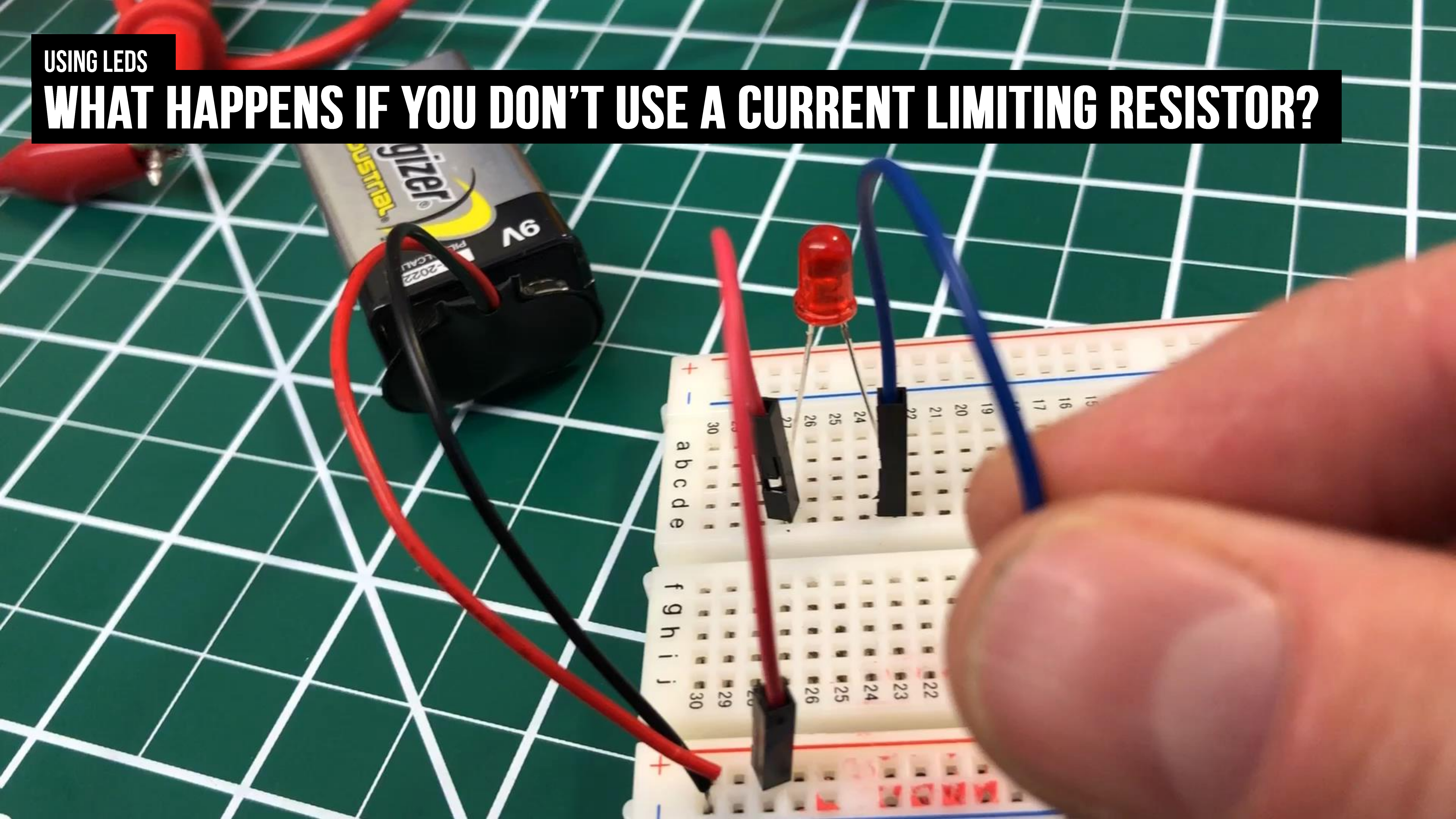
CURRENT LIMITING RESISTOR CAN BE ON EITHER SIDE OF LED

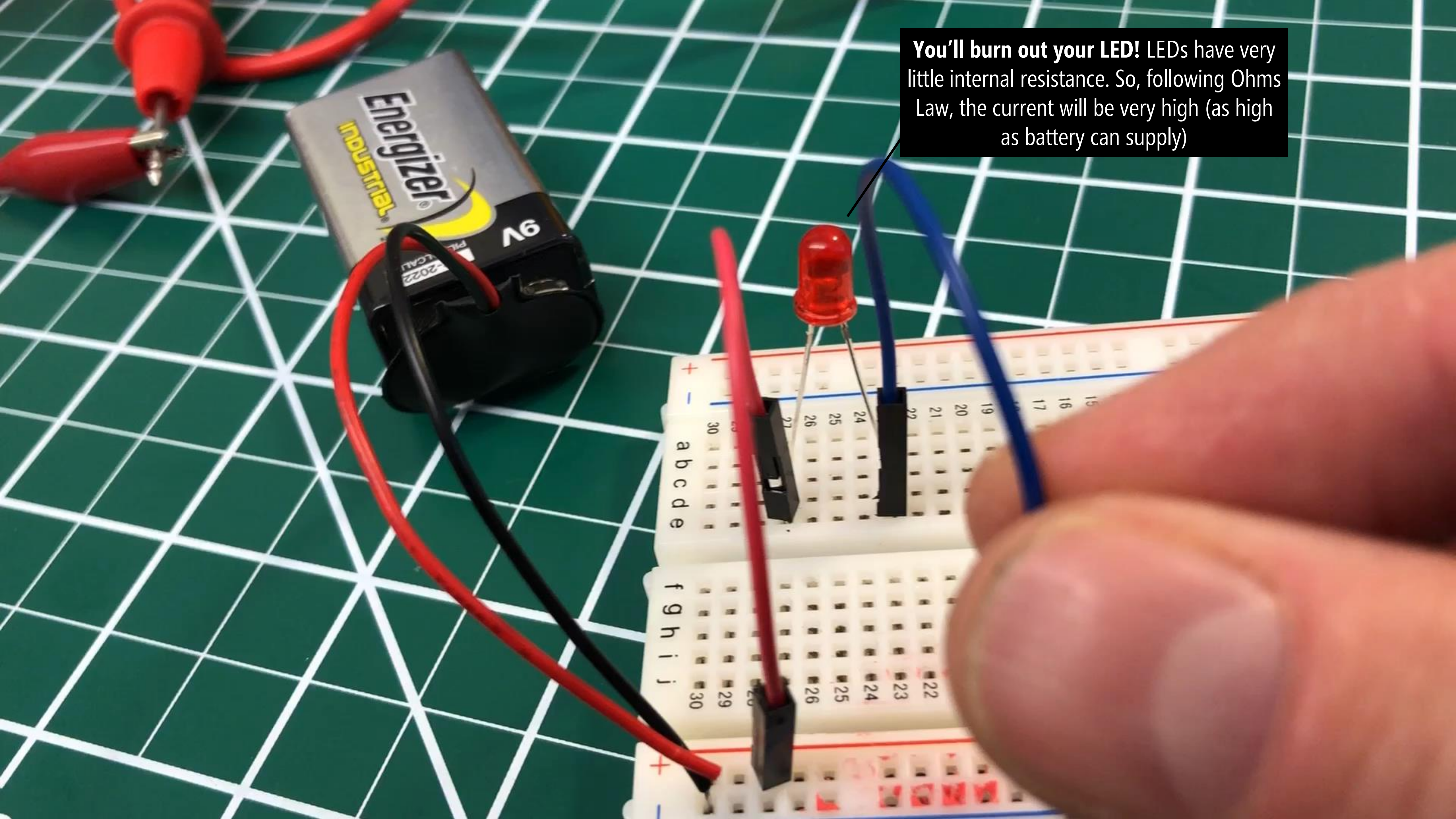
The current limiting resistor can be on either side of the LED (this can be shown with Ohm's Law, which we will soon learn about)





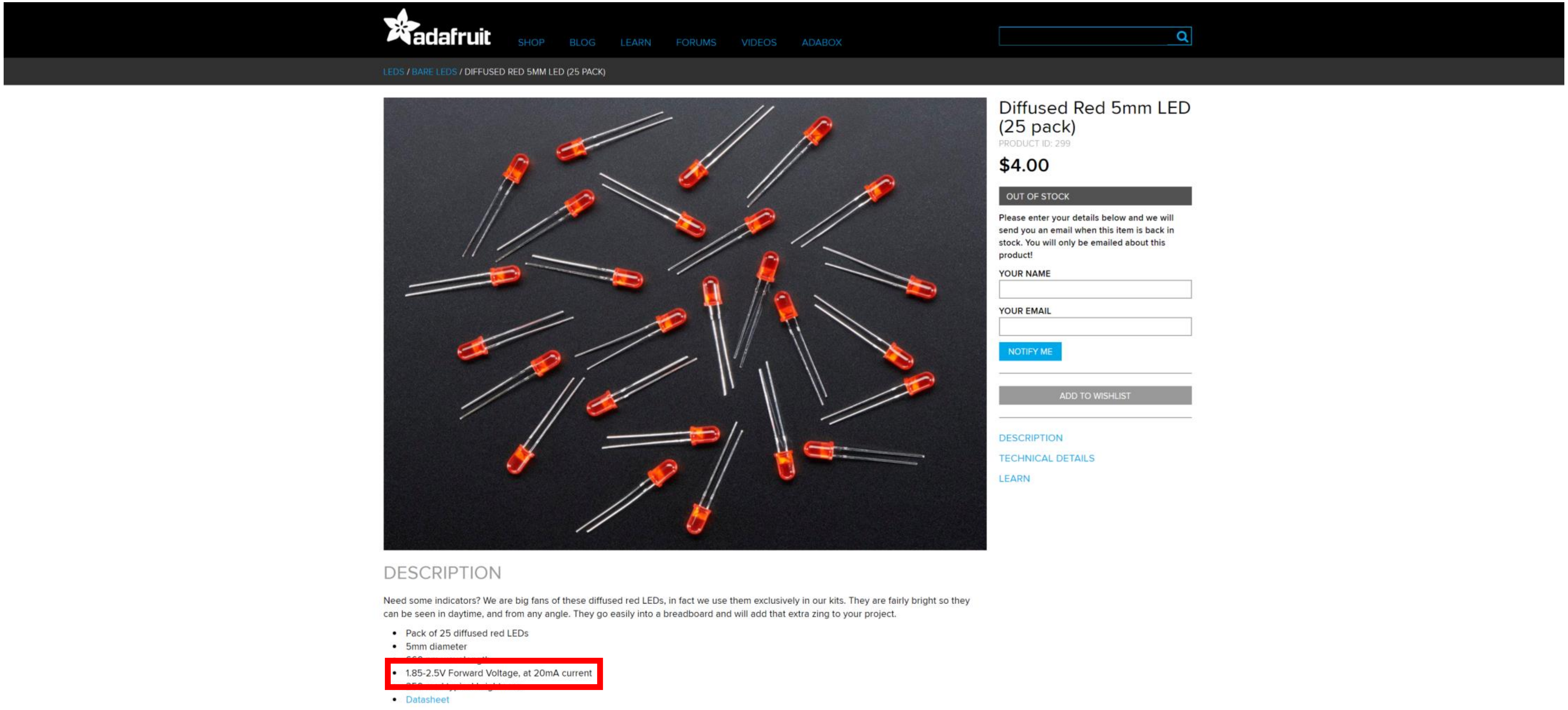
WHAT HAPPENS IF YOU DON'T USE A CURRENT LIMITING RESISTOR?




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

DIODES: FORWARD VOLTAGE

A diode (including an LED) won't allow current through unless a **forward voltage** condition is met. The LED's 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

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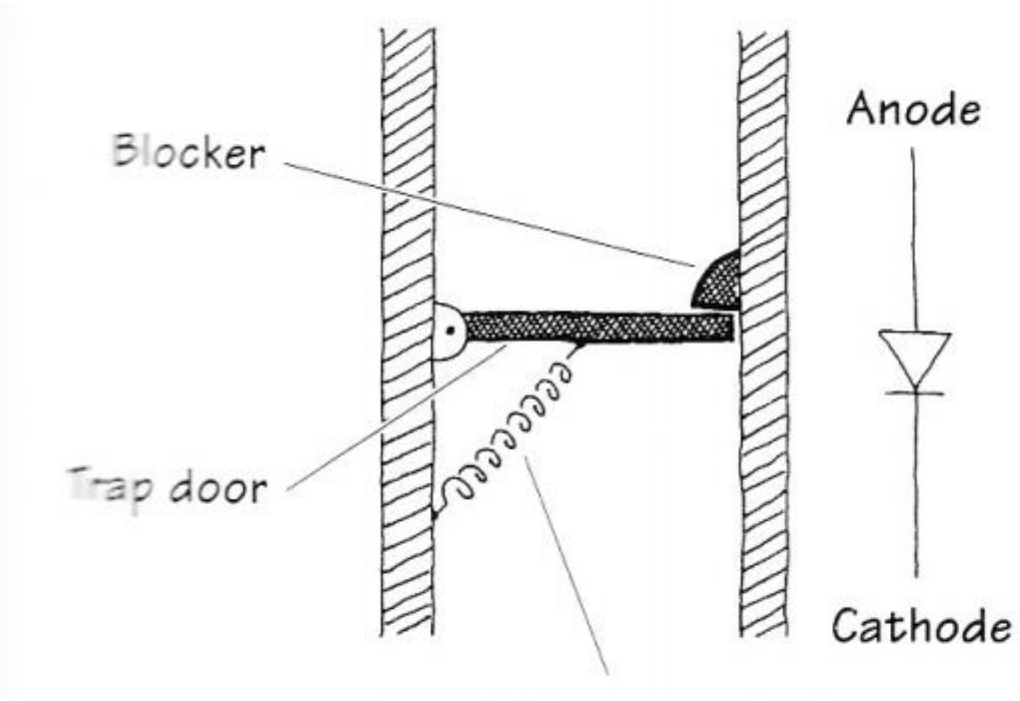
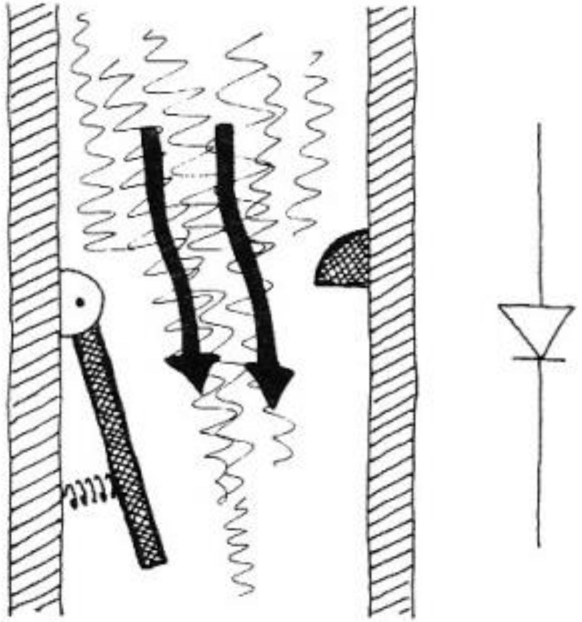
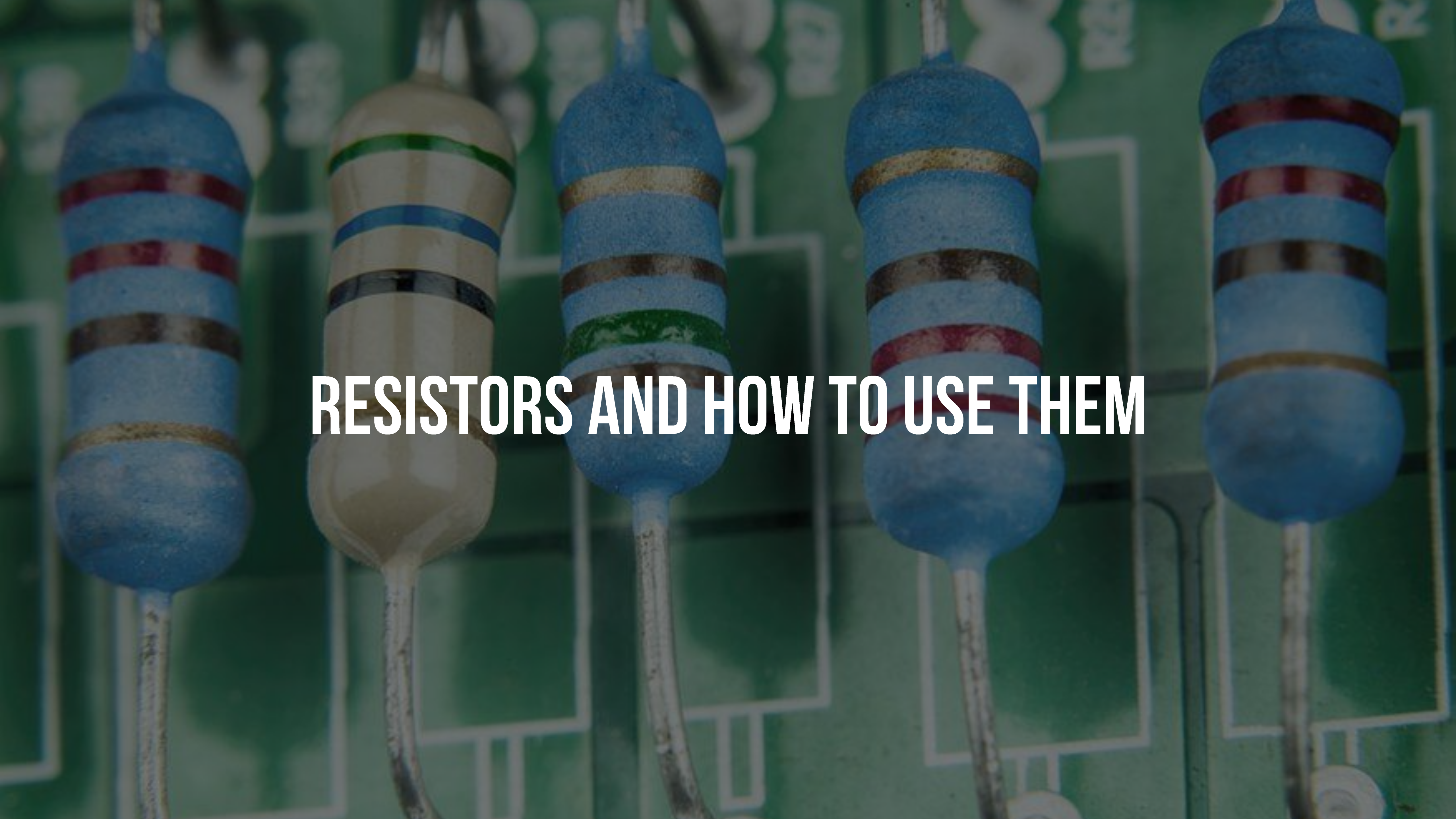


Imagine this trap door won't open unless a certain water pressure threshold is met (this is the forward voltage).

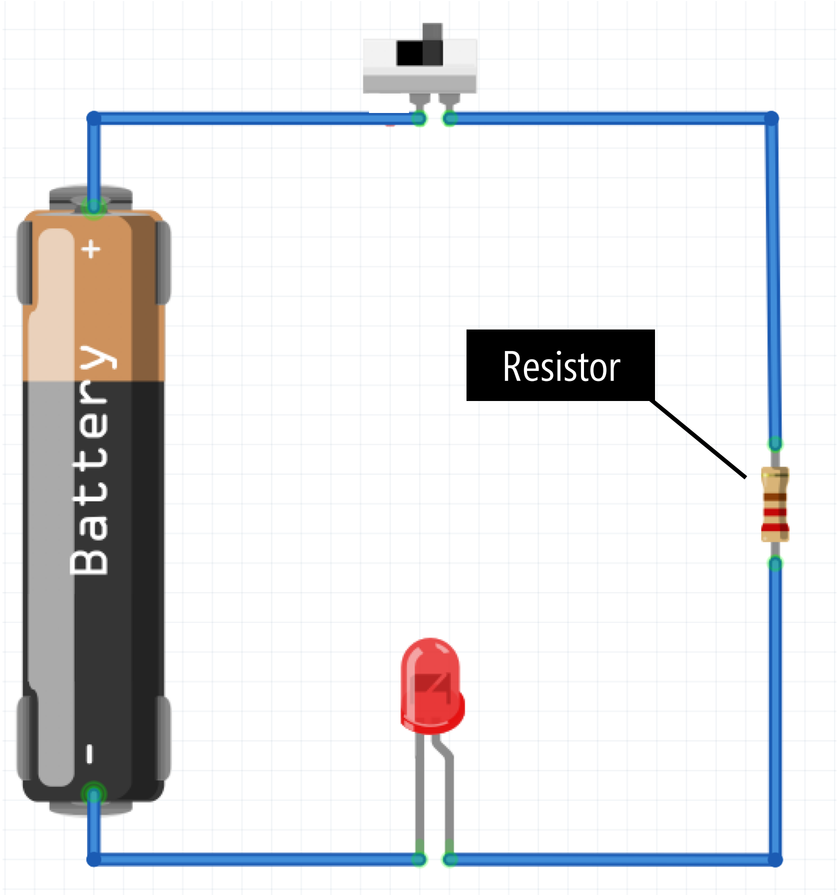


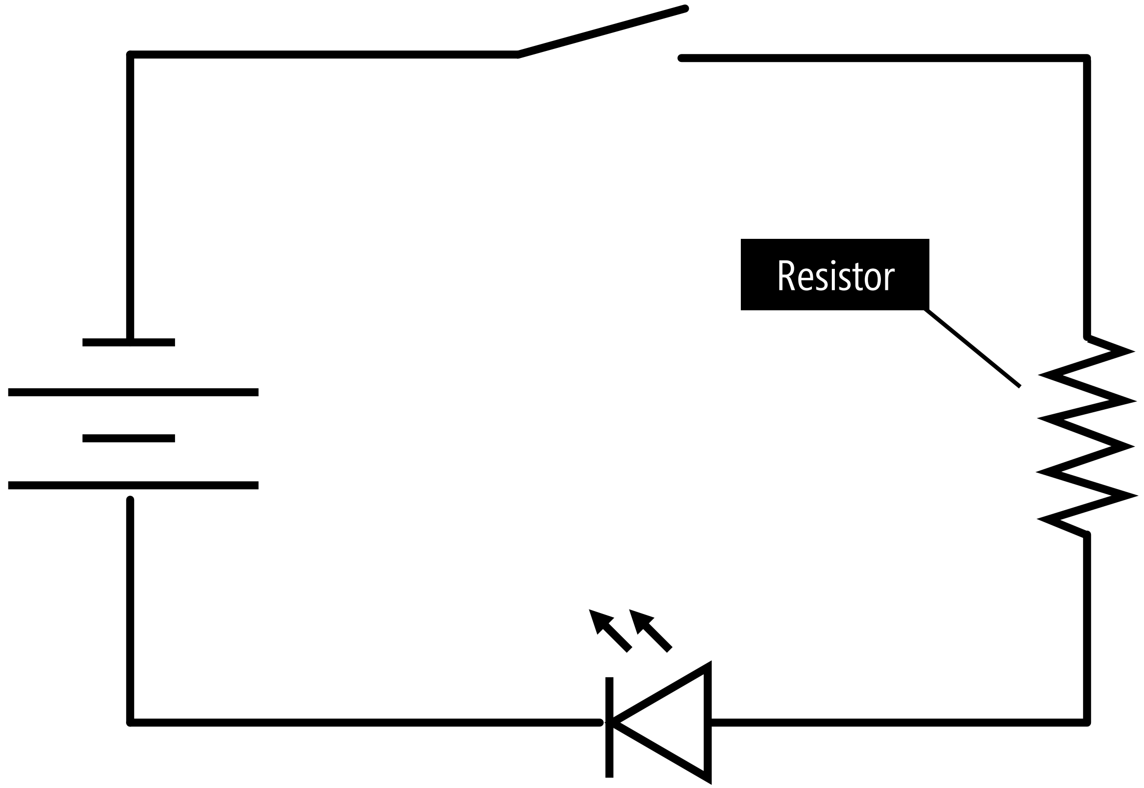
Once the threshold is met, the trap door opens and water (current) passes through.

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


RESISTORS AND HOW TO USE THEM

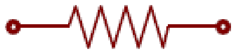
WHAT IS A RESISTOR?





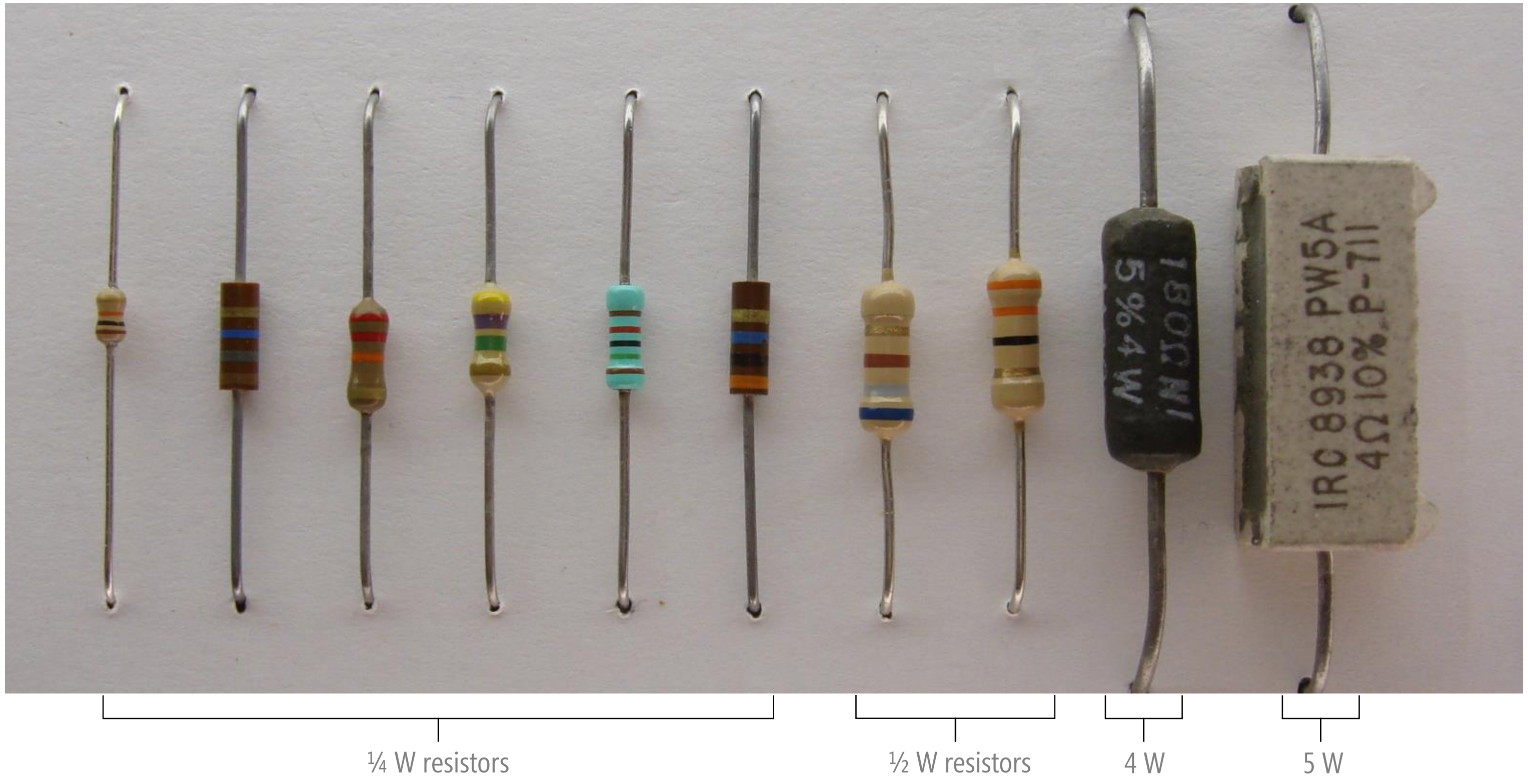
WHAT IS A RESISTOR?

American-Style Symbol



International-Style Symbol

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



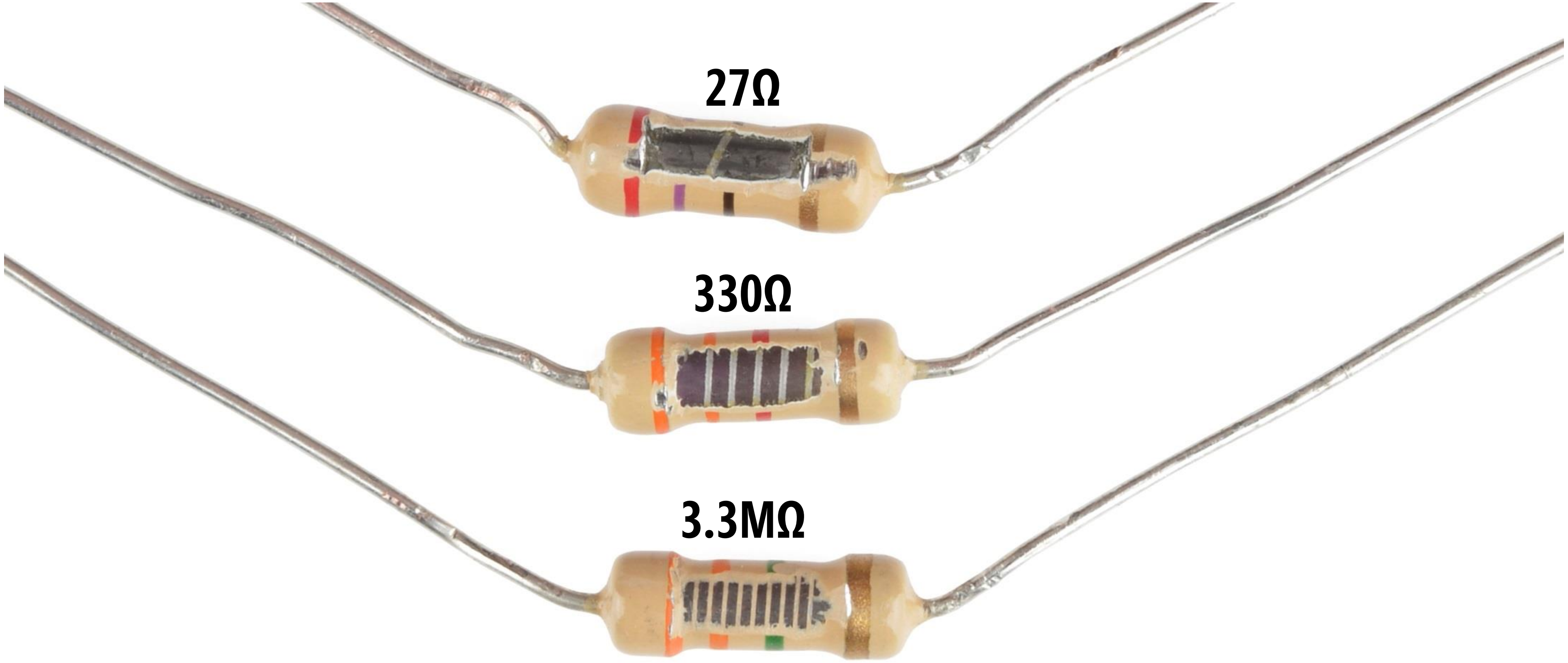
Resistors have no polarity so you can put them into a circuit in either orientation.

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.

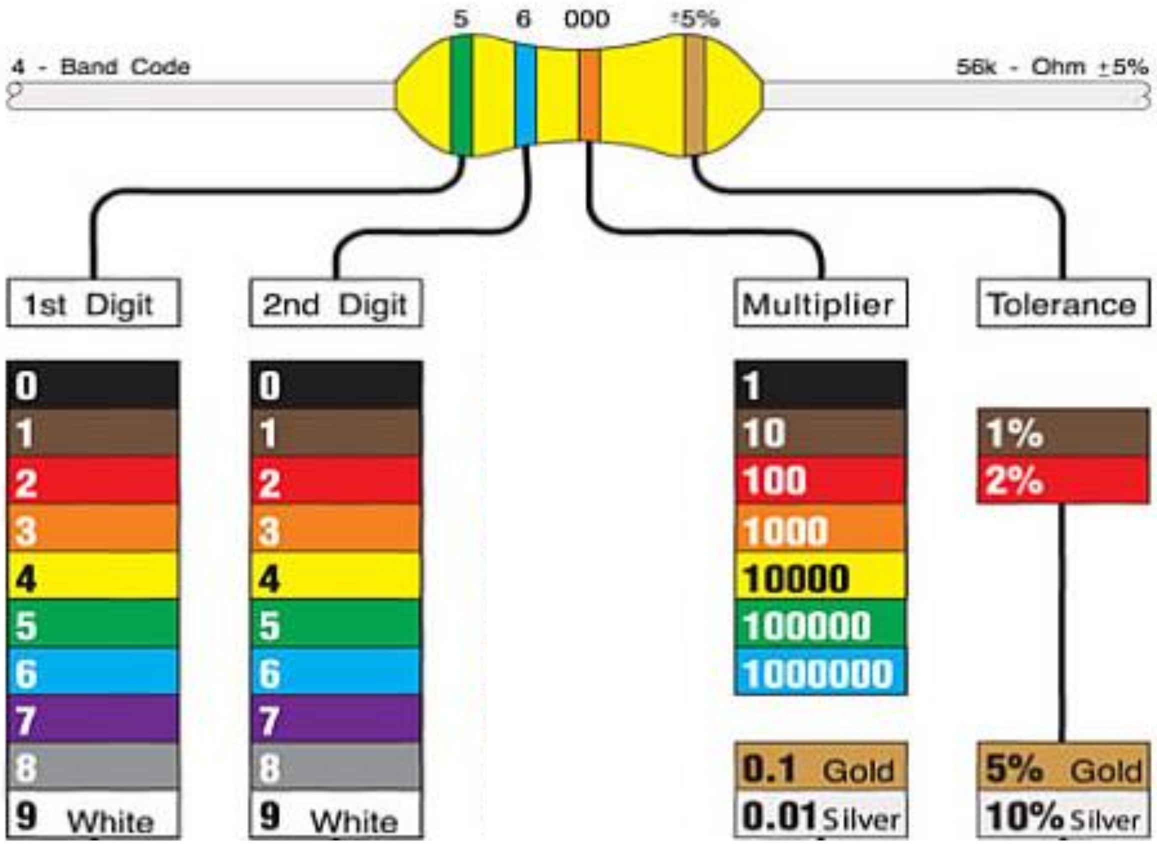


Source: https://learn.sparkfun.com/tutorials/resistors

READING A RESISTOR'S VALUE

Resistors have color-coded stripes indicating their resistance value

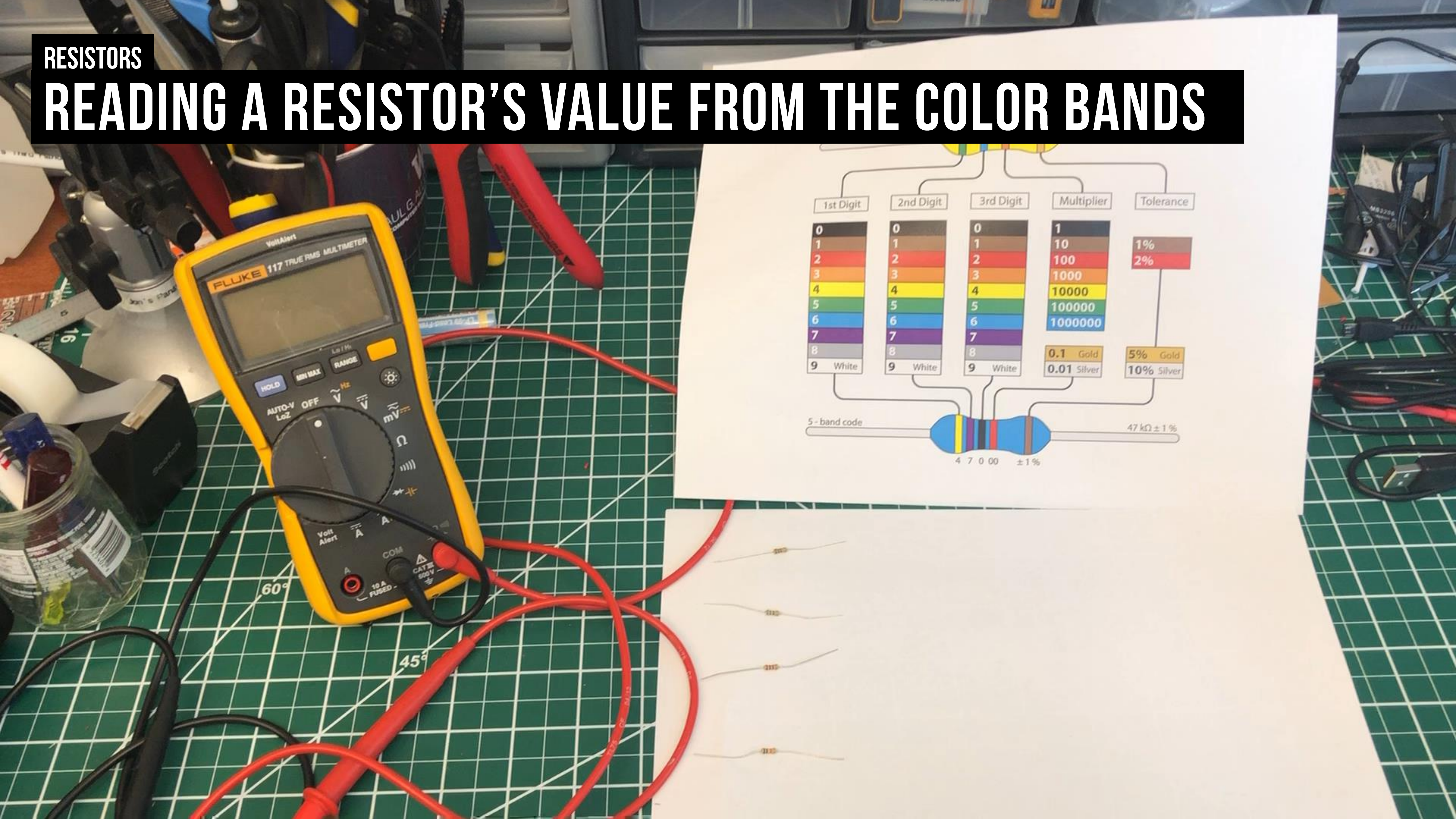
The tolerance stripe is always gold (5%) or silver (10%), which enables you to orient the resistor to read left-to-right

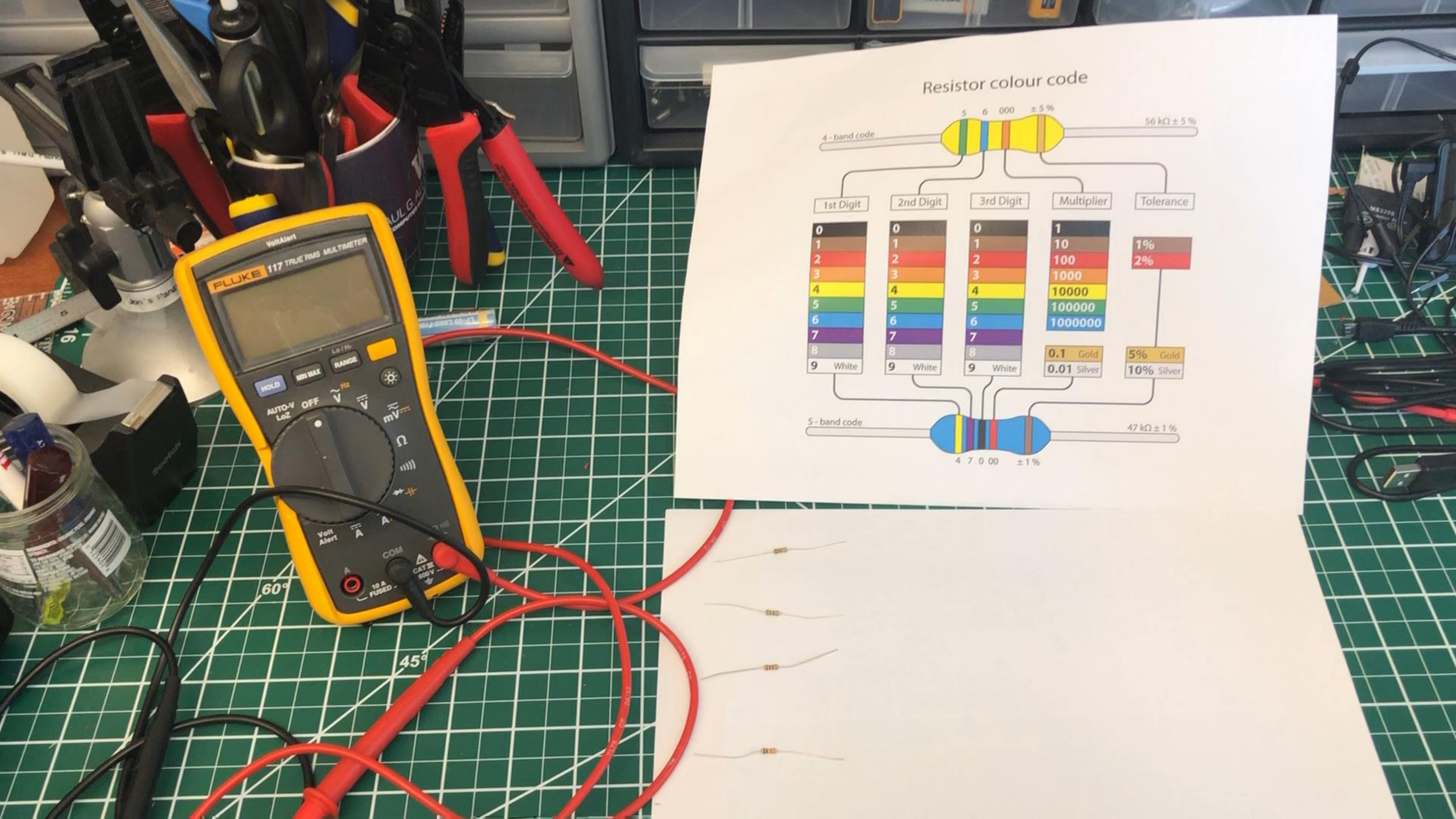


Source: https://www.electro-tech-online.com/tools/images/cheat-sheets-resistor.gif

RESISTORS

READING A RESISTOR'S VALUE FROM THE COLOR BANDS

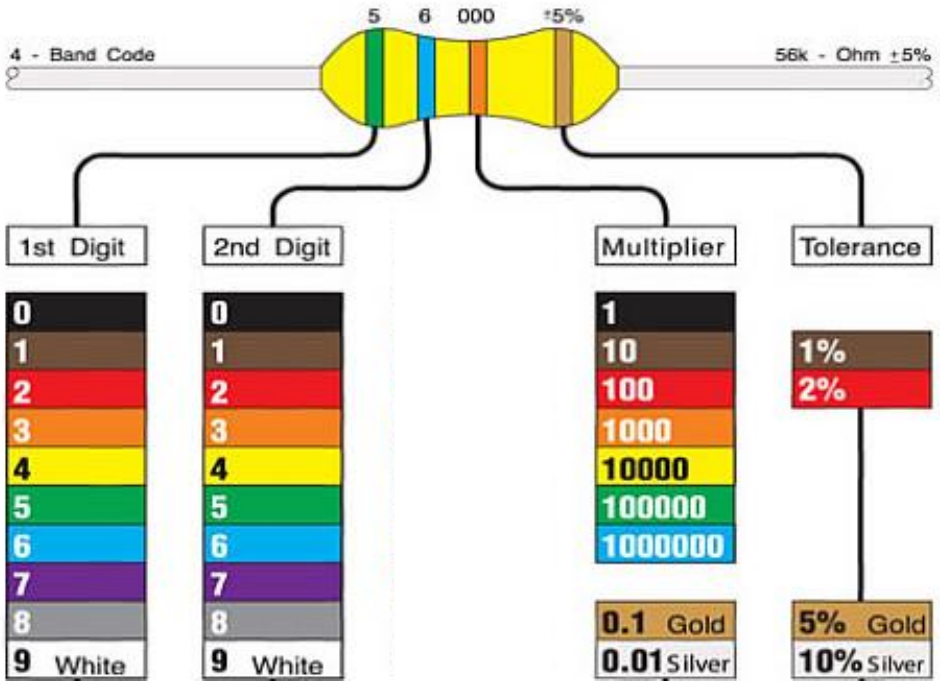




Resistor colour code
4 - band code
5 6 000 ± 5 %
56 kΩ ± 5 %
1st Digit
2nd Digit
3rd Digit
Multiplier
Tolerance
0 1 2 3 4 5 6 7 8 9 White
1 10 100 1000 10000 100000 1000000
0.1 Gold
0.01 Silver
1% 2%
5% Gold
10% Silver
5 - band code
4 7 0 00 ± 1 %
47 kΩ ± 1 %
FLUKE 117 TRUE RMS MULTIMETER
VoltAlert
HOLD
MIN MAX
RANGE
AUTO-V LoZ
OFF
COM

EXERCISE: READING A RESISTOR'S VALUE

Resistors have color-coded stripes indicating their resistance value



What is the value of this resistor?

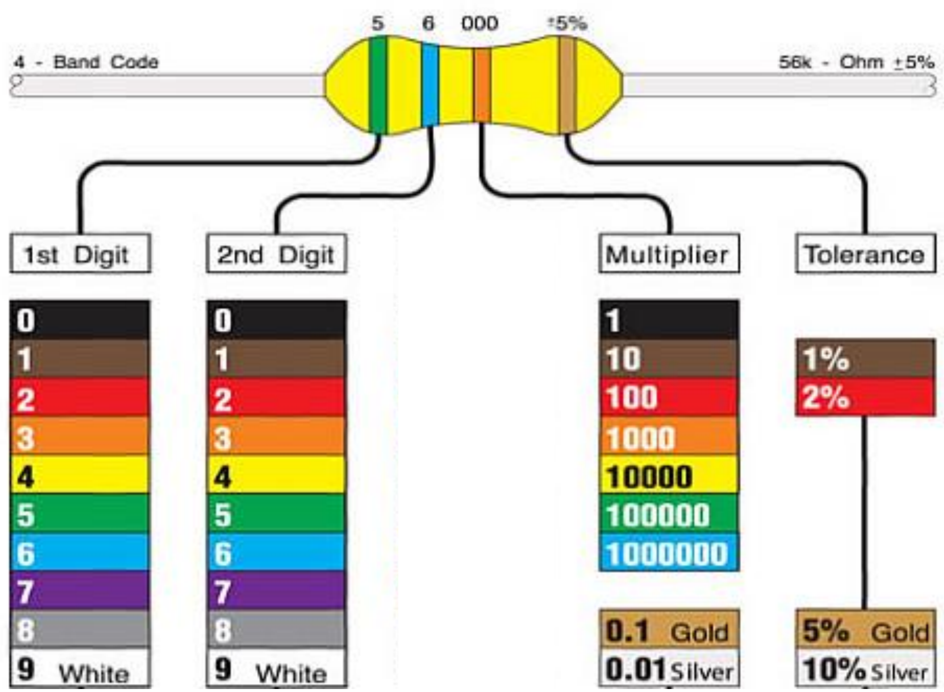
Red, red, brown

What is the value of this resistor?

Brown, black, orange

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= 2, 2, 10 = 22 * 10 = 220Ω

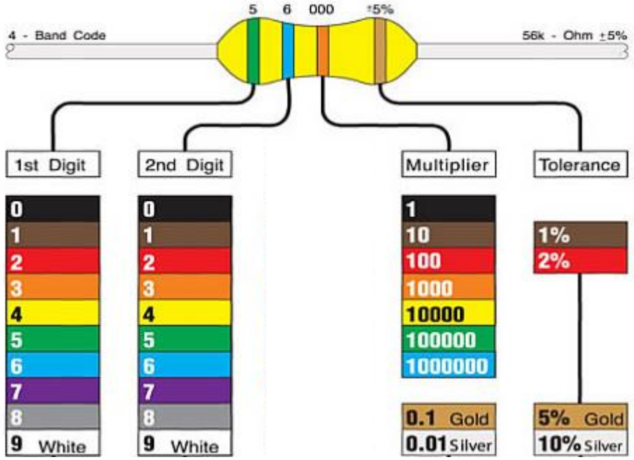
What is the value of this resistor? 10,000Ω or 10KΩ

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

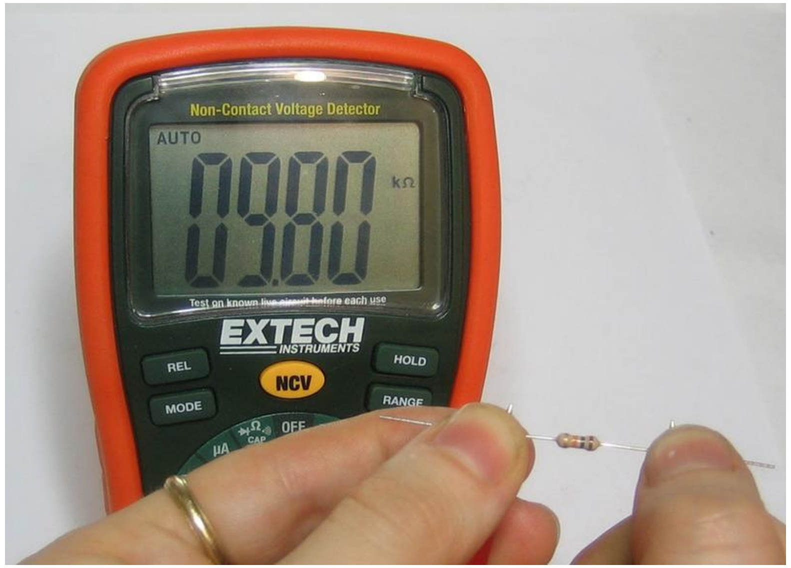
Source: https://www.electro-tech-online.com/tools/images/cheat-sheets-resistor.gif

READING A RESISTOR: THREE STRATEGIES

1. Keep Your Resistors Organized
I typically buy the SparkFun Resistor Kit, which comes organized by resistor value. We purchased ~10 of these for the studio.



2. Resistor Chart (or from Memory)
Obviously, you can also use a resistor chart (or your memory) but you still have to find the resistor you're looking for! ☺

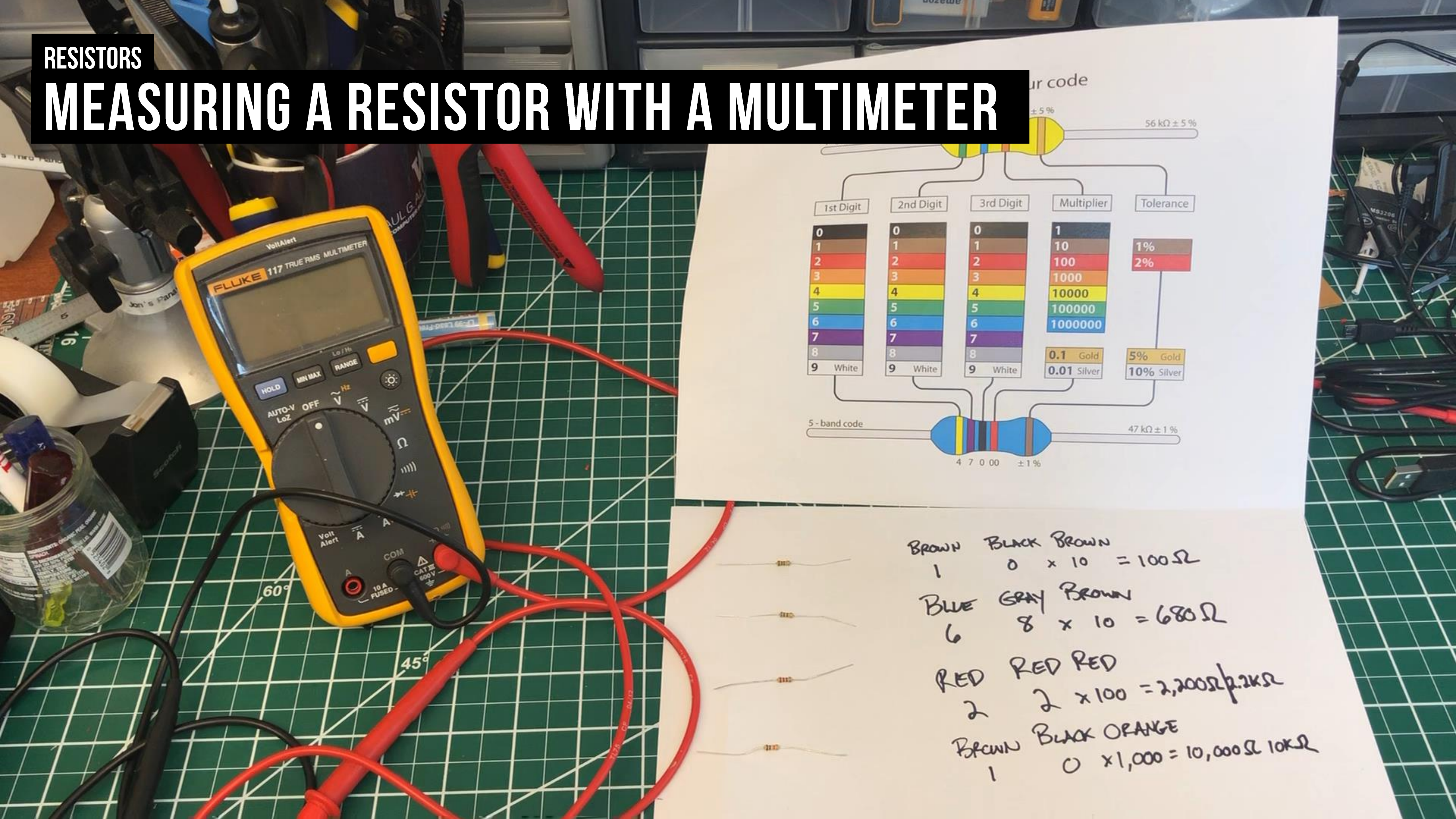


3. Use a Multimeter
Make sure that the resistor is not connected to anything else and switch the multimeter to its resistance measurement setting

FASTEST → SLOWEST

RESISTORS

MEASURING A RESISTOR WITH A MULTIMETER



ACTIVITY

BUILD YOUR FIRST CIRCUIT: RESISTOR + LED

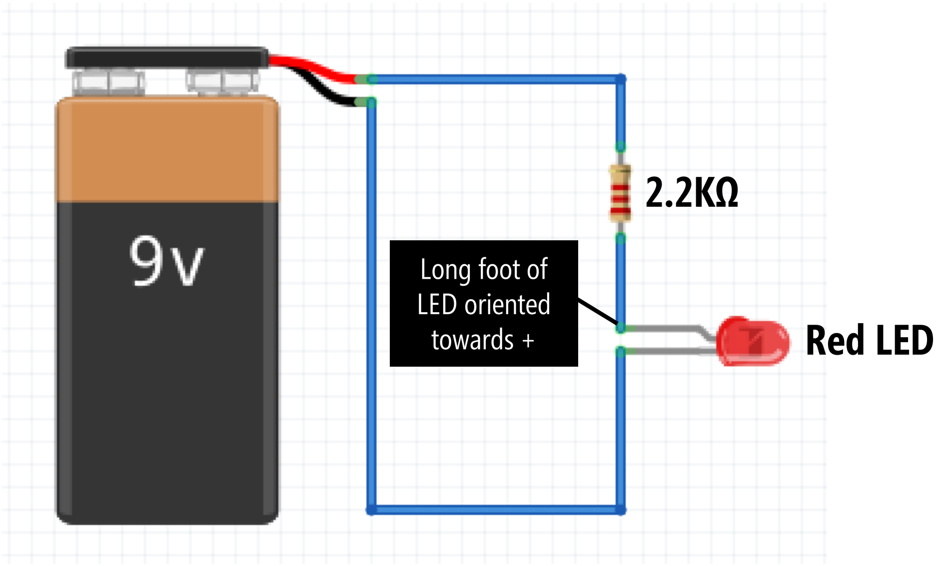
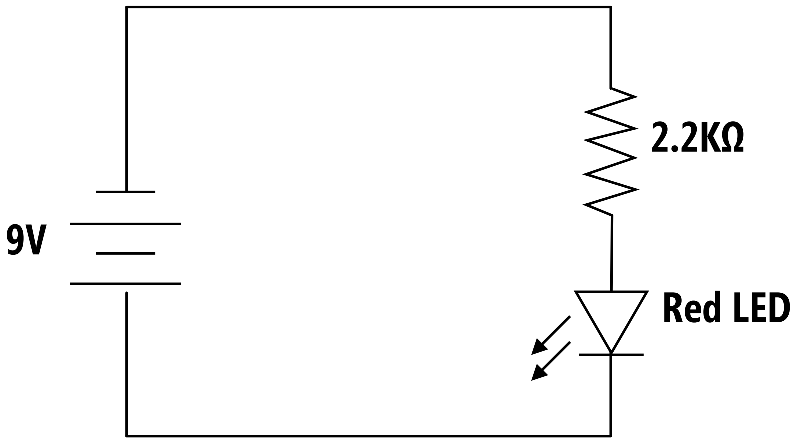


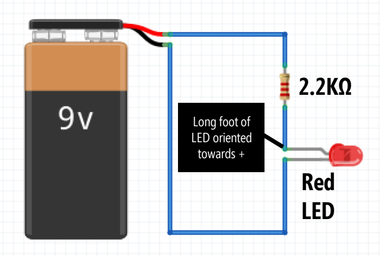
DIAGRAM VIEW

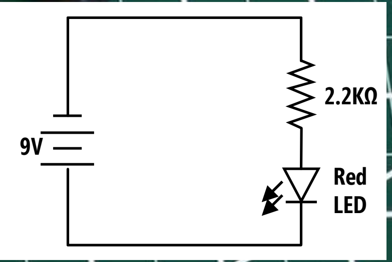


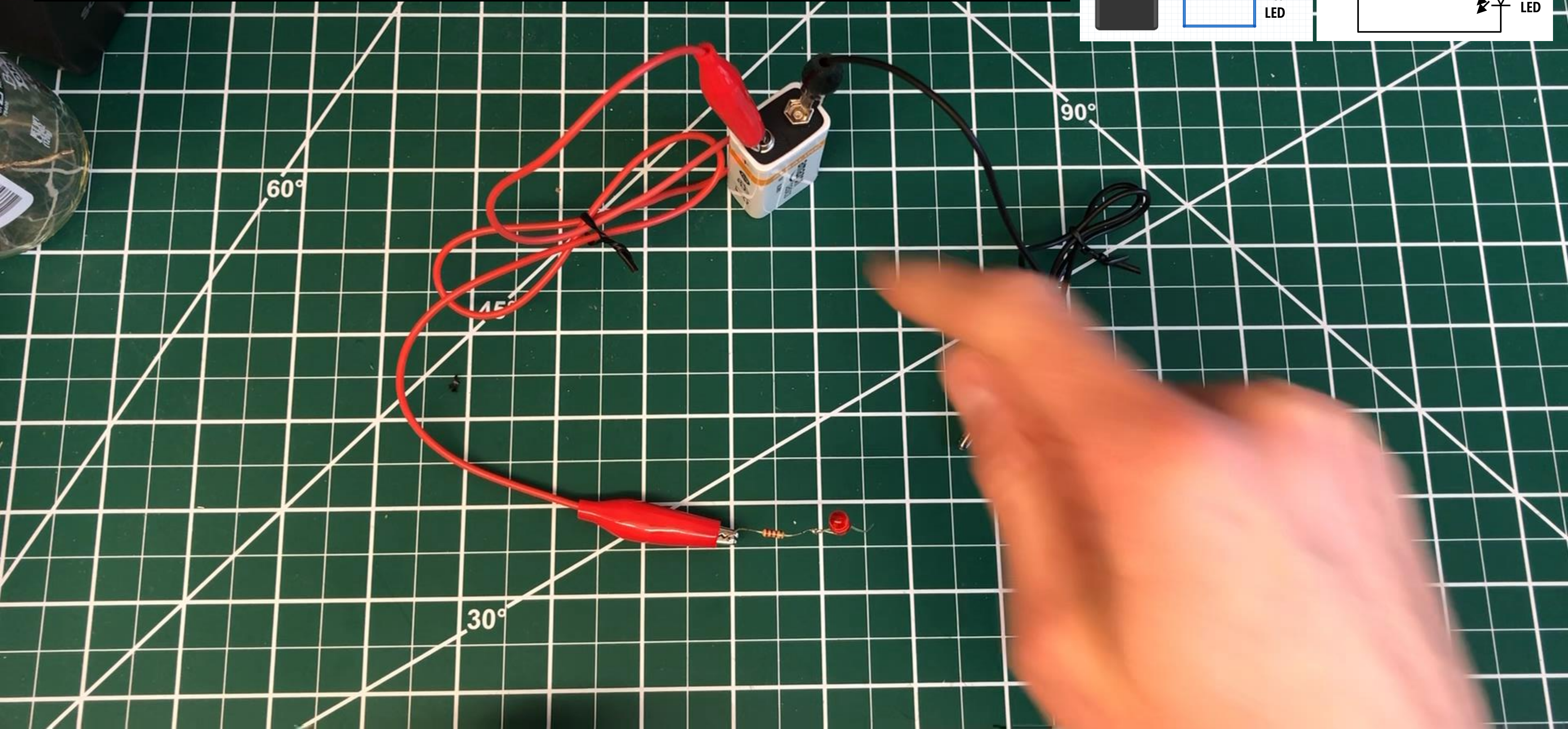
SCHEMATIC VIEW

ACTIVITY

BUILD YOUR FIRST CIRCUIT: RESISTOR + LED







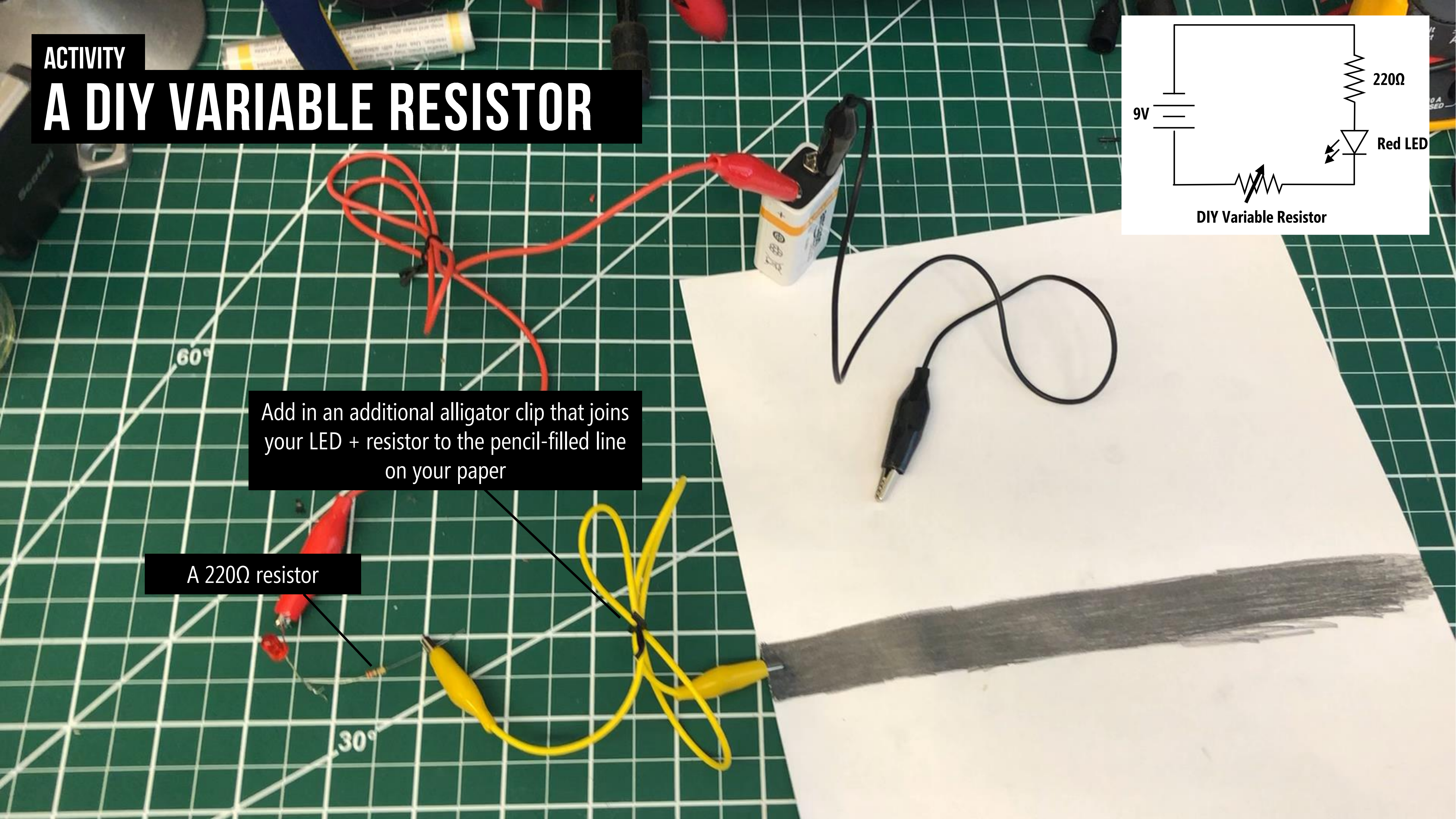
ACTIVITY

A DIY VARIABLE RESISTOR

Make something that looks like this. Press hard. The more graphite, the better!

ACTIVITY

A DIY VARIABLE RESISTOR

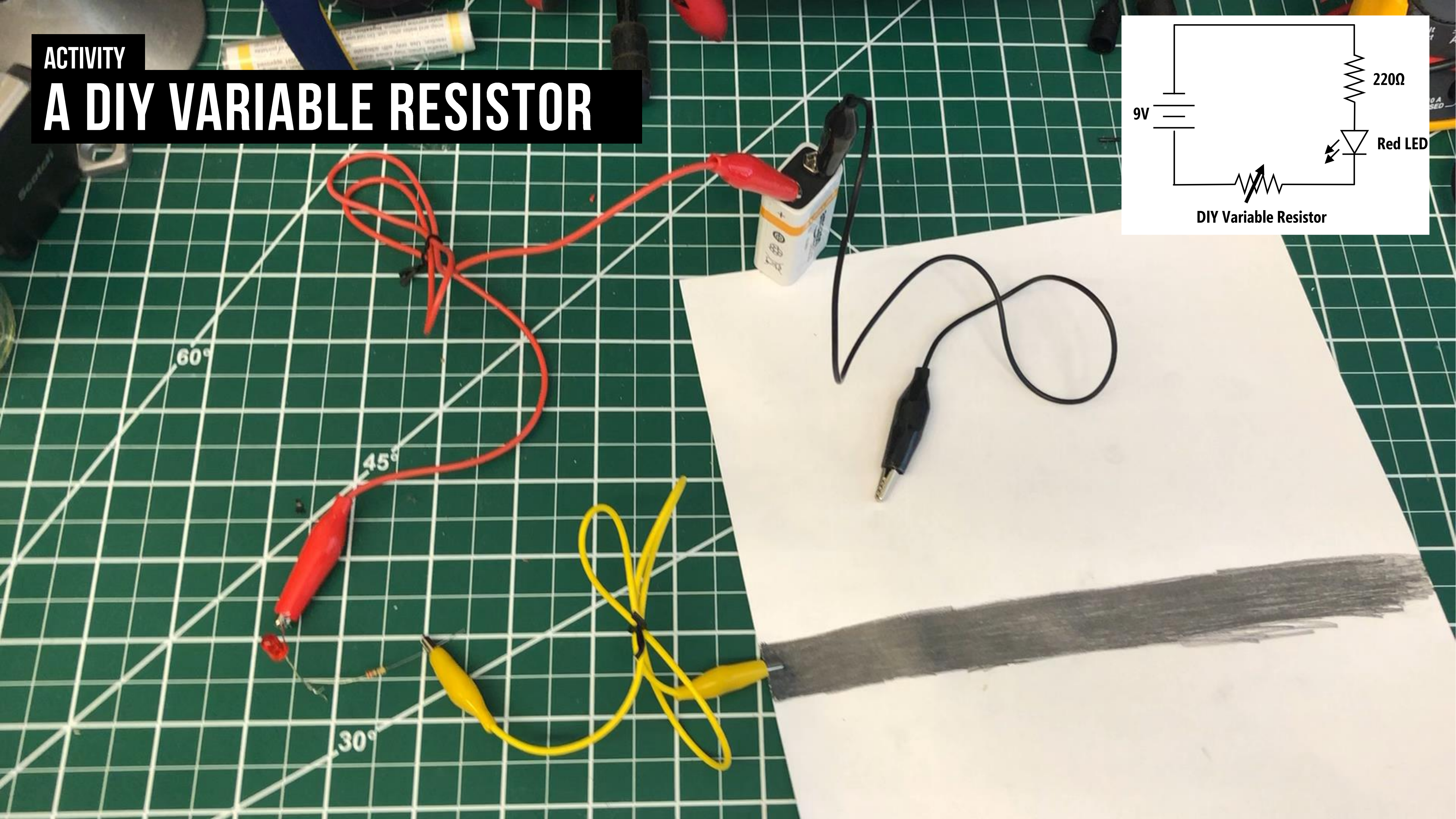


Add in an additional alligator clip that joins your LED + resistor to the pencil-filled line on your paper

A 220Ω resistor

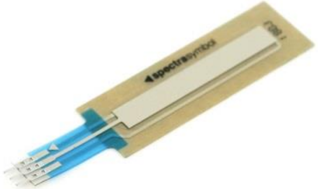
ACTIVITY

A DIY VARIABLE RESISTOR



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

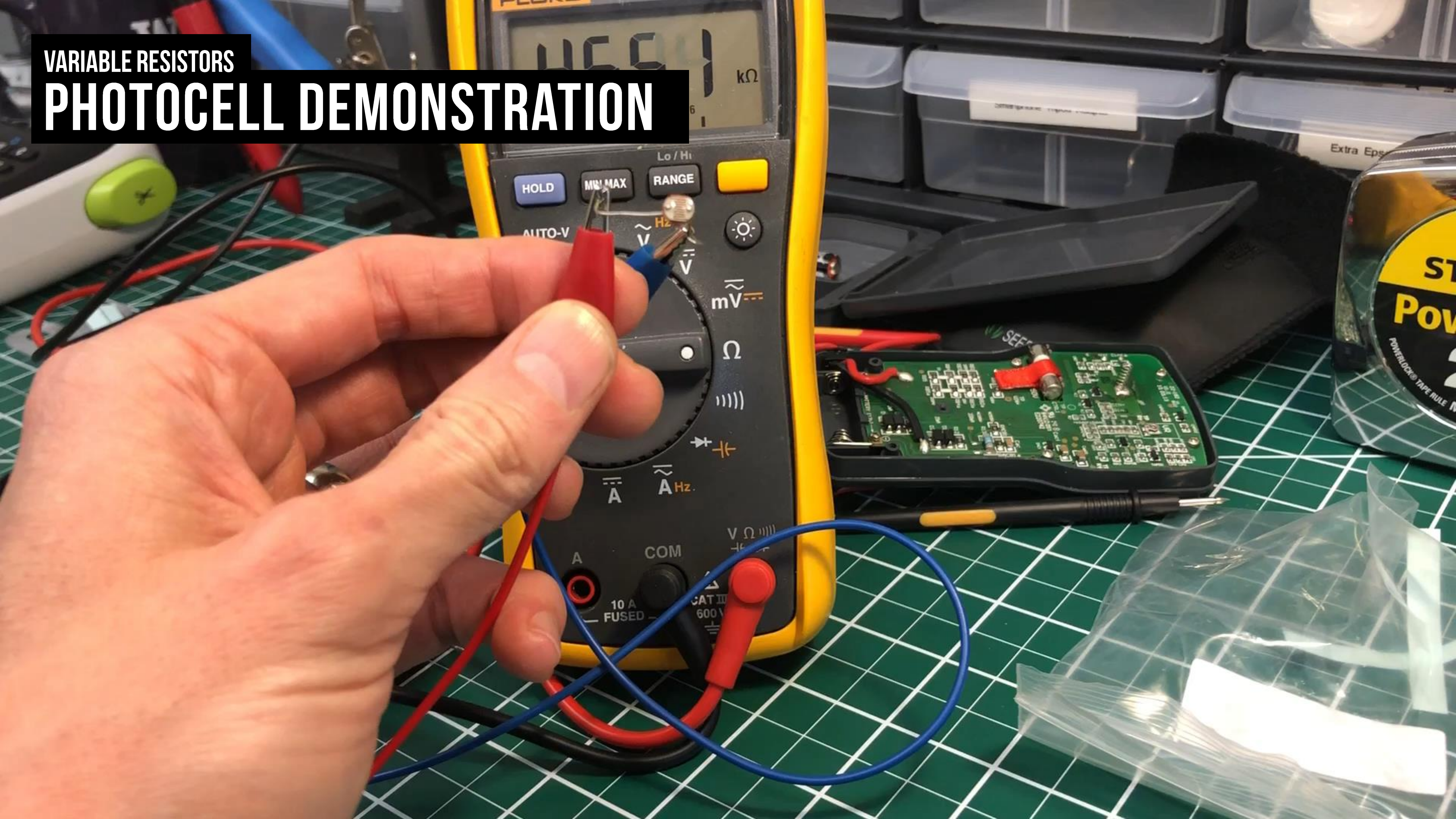
Force Resistive Sensor 0.5″; $6.95

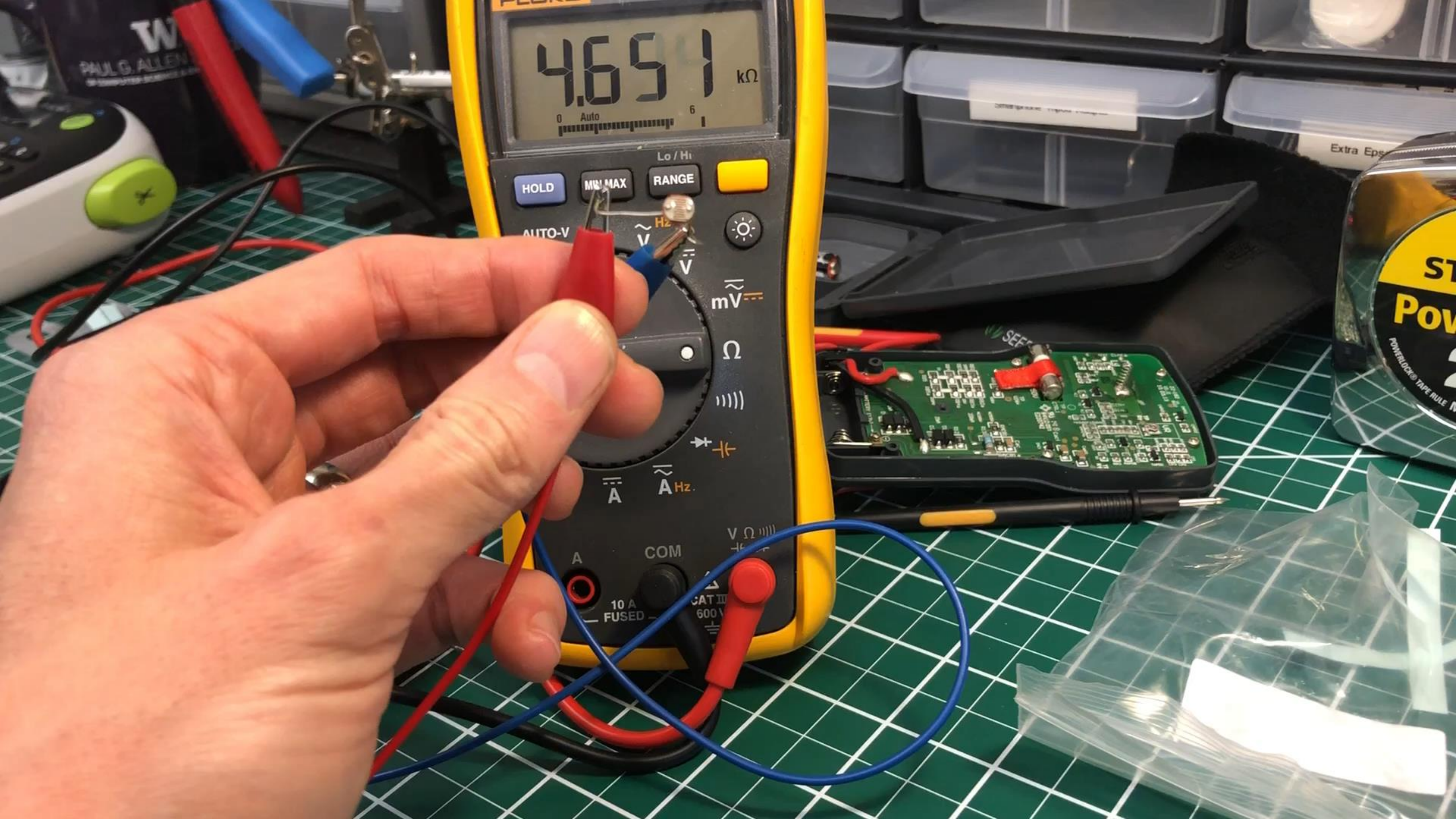
Flex Sensor 4.5″; $12.95

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

VARIABLE RESISTORS

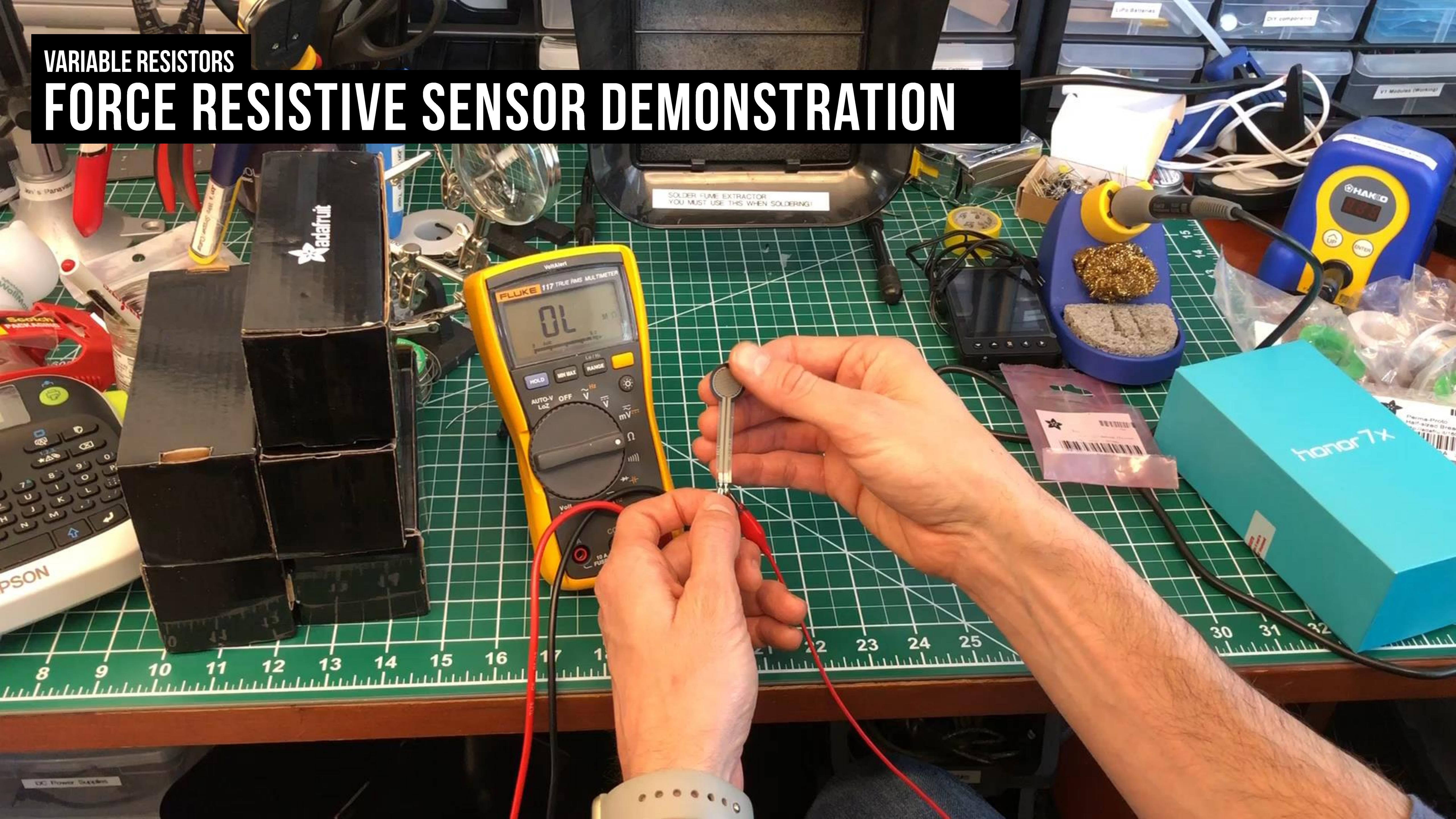
PHOTOCELL DEMONSTRATION

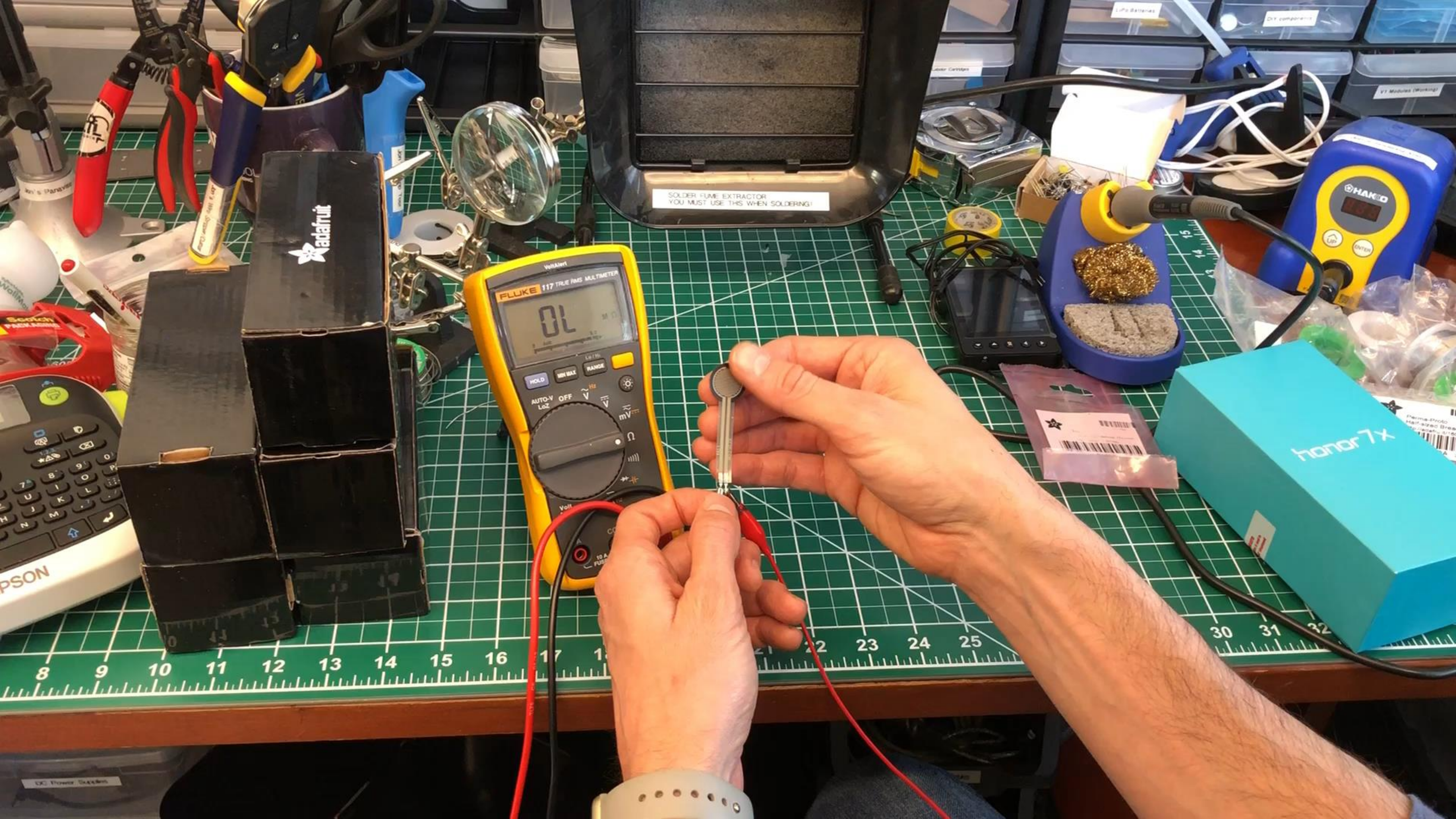



4.651 kΩ
0 Auto 6
Lo / Hi
HOLD
MIN MAX
RANGE
AUTO-V
mV
Ω
A
COM
10 A FUSED
CAT III 600 V

VARIABLE RESISTORS

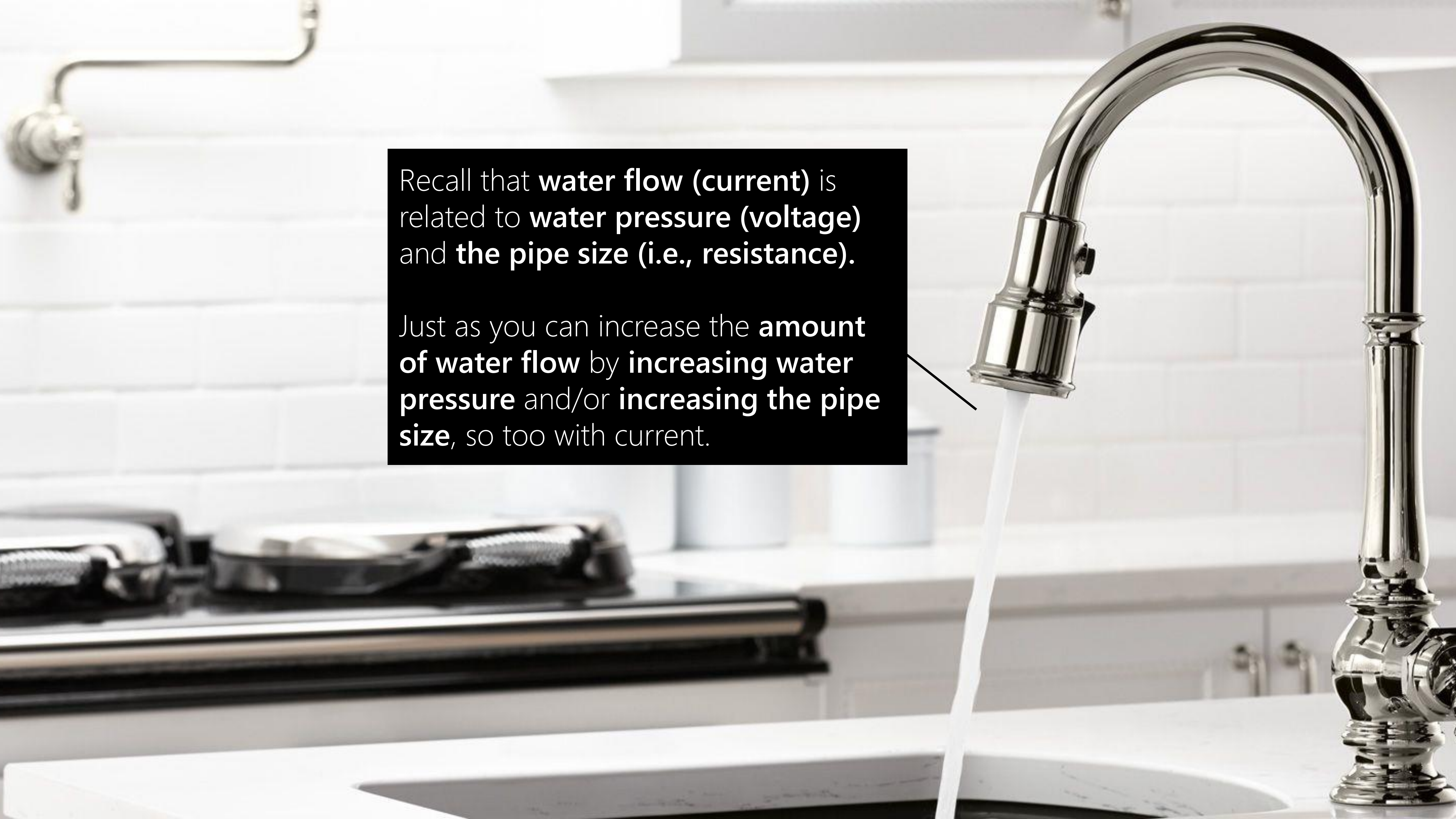
FORCE RESISTIVE SENSOR DEMONSTRATION




SOLDER FUME EXTRACTOR
YOU MUST USE THIS WHEN SOLDERING!
adafruit
FLUKE 117 TRUE RMS MULTIMETER
0L
HOLD
MIN MAX
RANGE
honor 7x

But how do we know how much **current** (measured in **amps**) is flowing through our circuit? And **why do we care**?


Recall that **water flow (current)** is related to **water pressure (voltage)** and **the pipe size (i.e., resistance)**

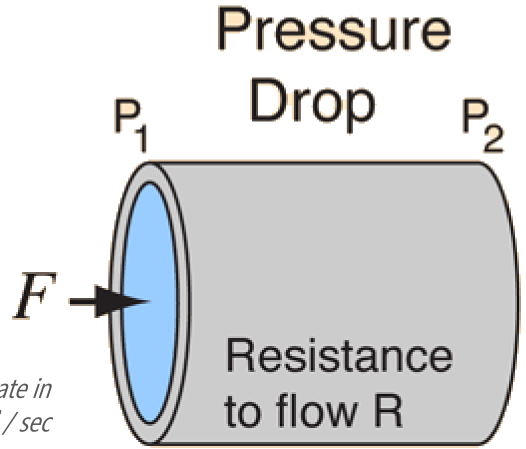


Recall that **water flow (current)** is related to **water pressure (voltage)** and **the pipe size (i.e., resistance).**

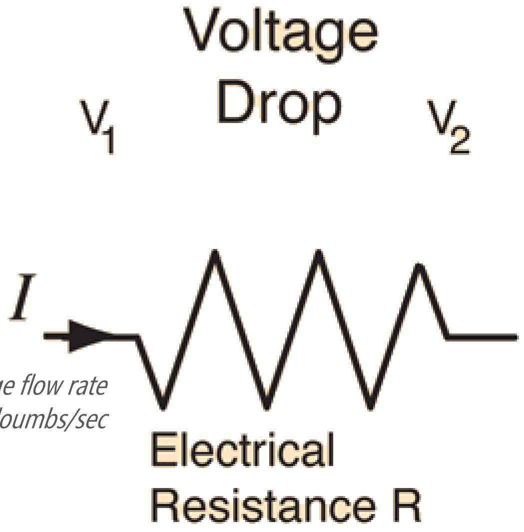
Just as you can increase the **amount of water flow** by **increasing water pressure** and/or **increasing the pipe size**, so too with current.

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

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

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

Poiseuille's Law for fluids

circa ~1838

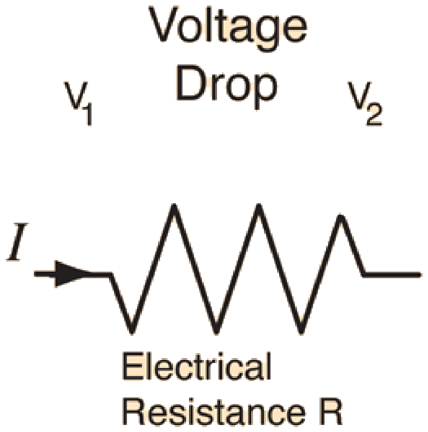
Ohm's Law for electric circuits

circa ~1825

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

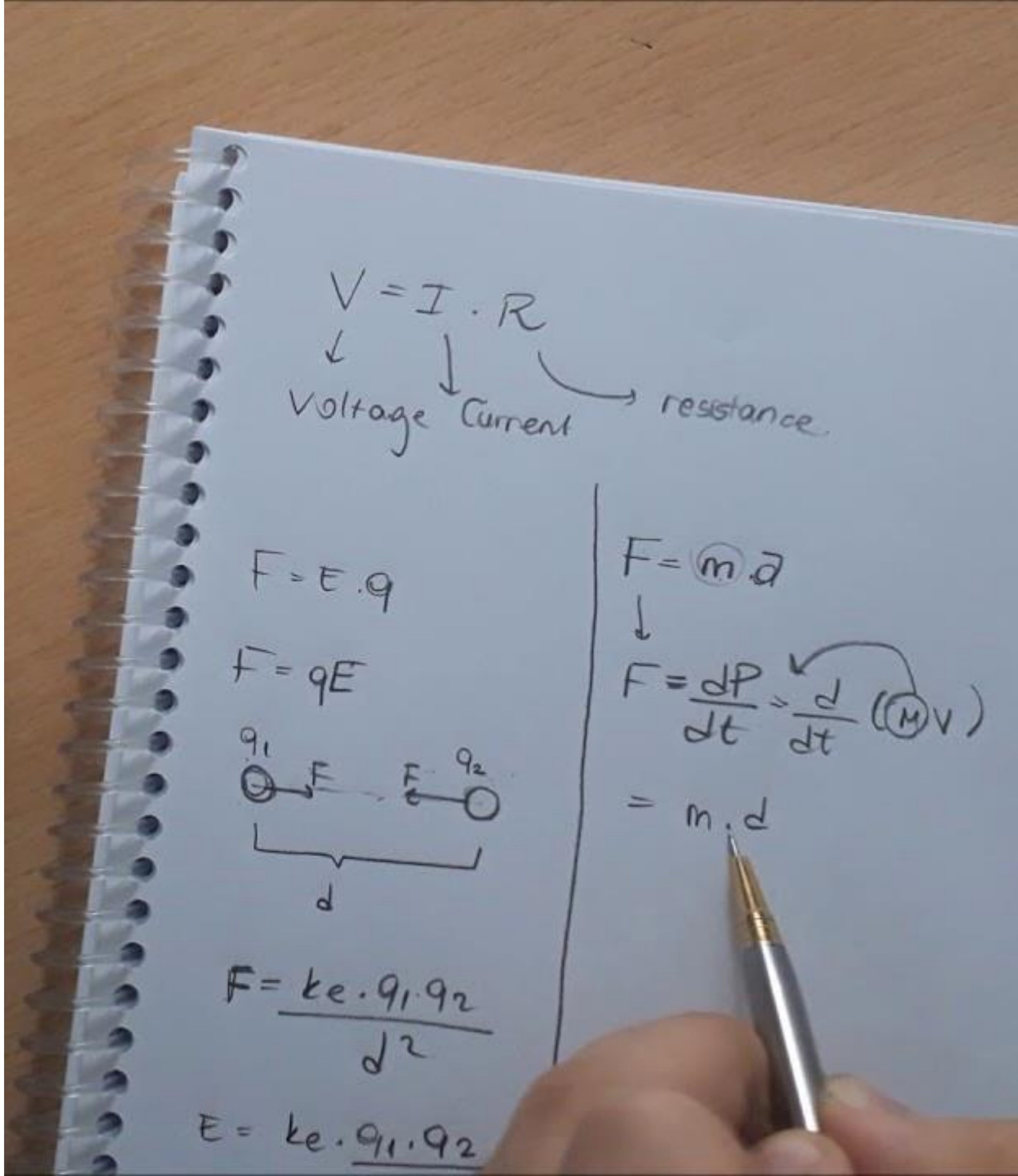
DIGGING INTO OHM'S LAW

Let's get out a pencil & paper ☺



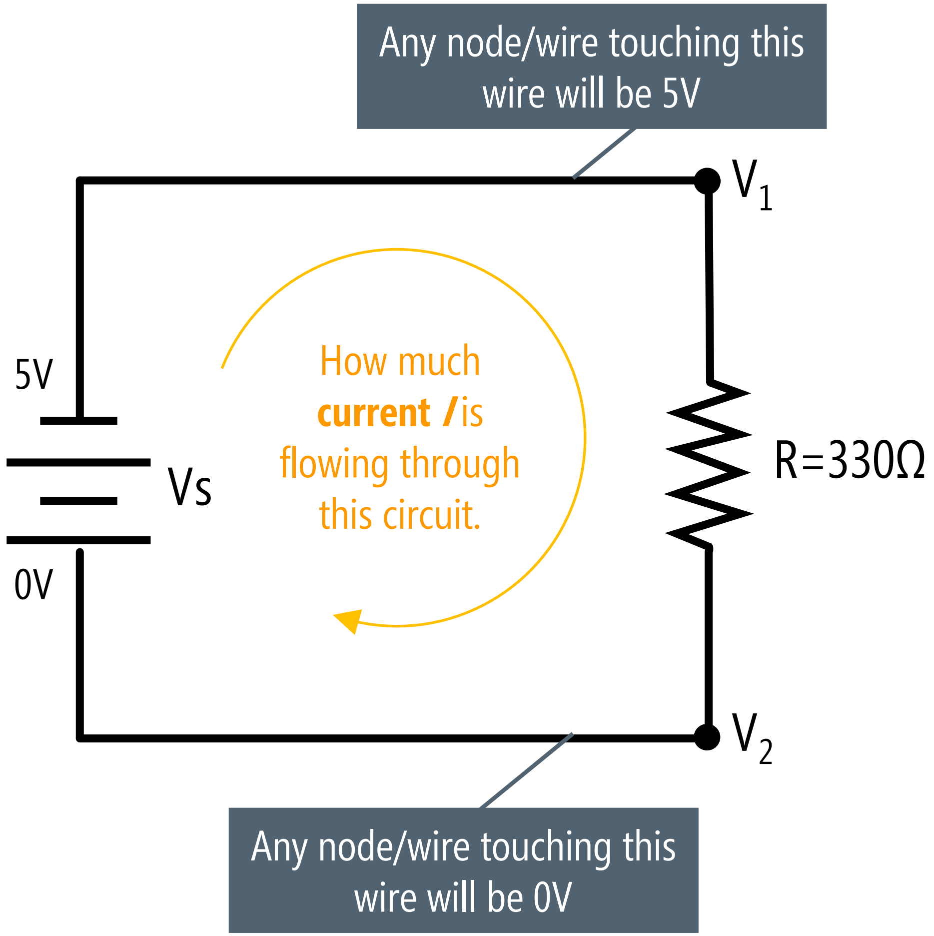
$$I = \frac{V_1 - V_2}{R}$$

Ohm's Law for electric circuits




EVERYTHING
IS
AWESOME

OHM'S LAW EXERCISE: SOLVE FOR CURRENT

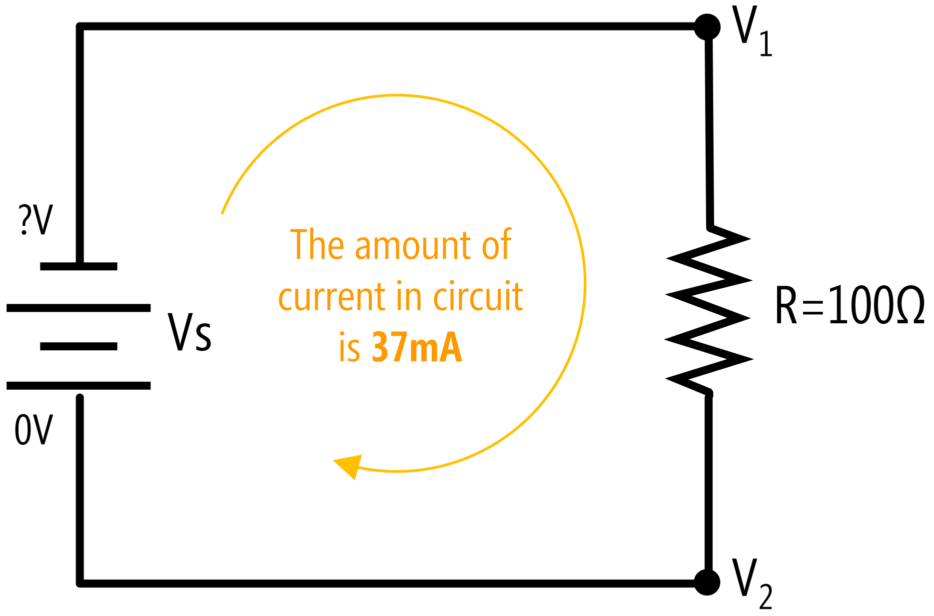


$$Current = I = \frac{V_{high\ potential} - V_{low\ potential}}{R}$$

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

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

OHM'S LAW EXERCISE: SOLVE FOR VOLTAGE

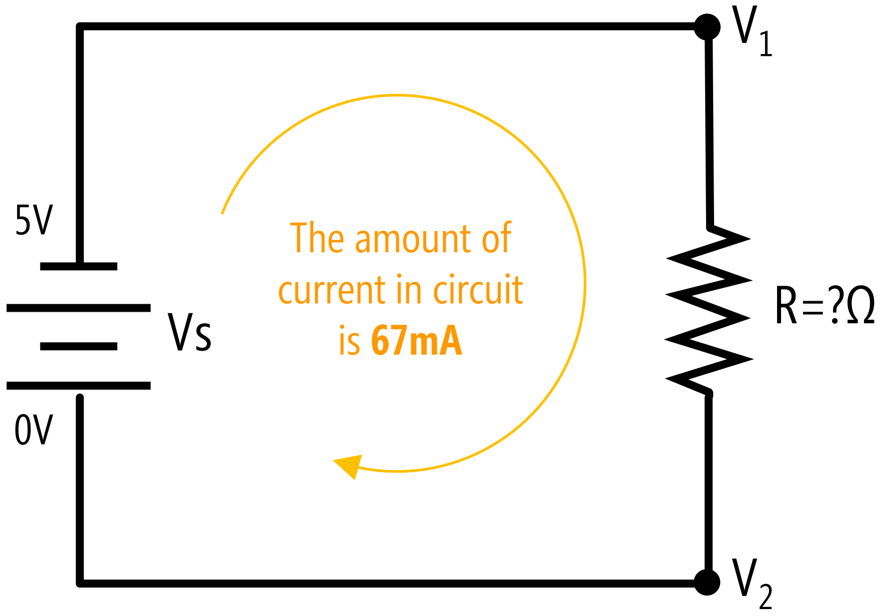


$$Current = I = \frac{V_{high\ potential} - V_{low\ potential}}{R}$$

$$Voltage = V = I * R$$

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

OHM'S LAW EXERCISE: SOLVE FOR RESISTANCE



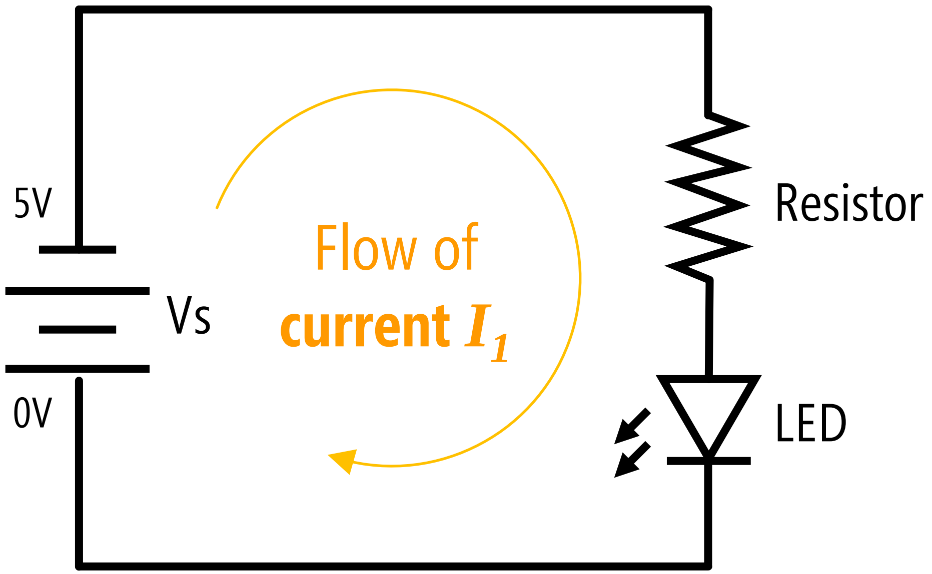
$$Current = I = \frac{V_{high\ potential} - V_{low\ potential}}{R}$$

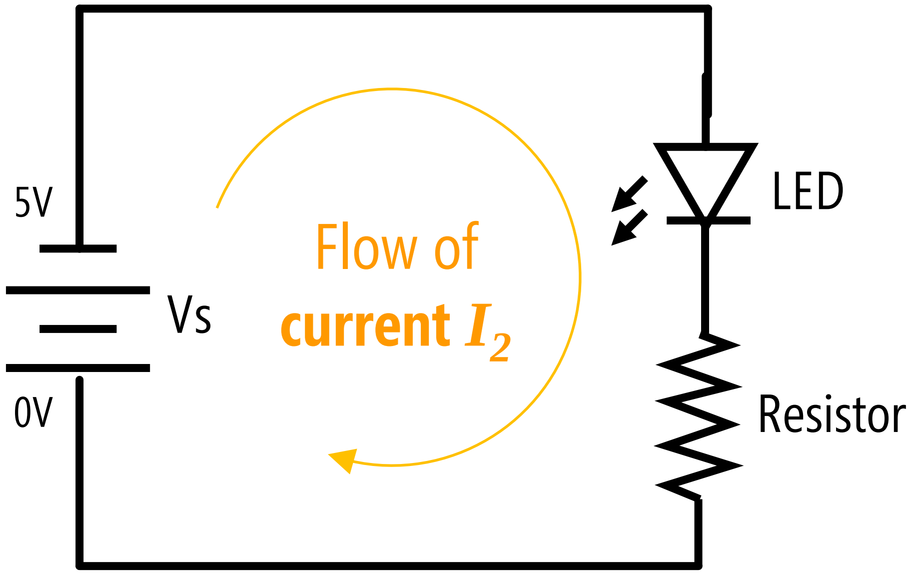
$$Resistance = R = \frac{V}{I}$$

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

WHAT'S THE DIFFERENCE?

Can we put a current limiting resistor after the LED instead of before in this circuit? Is there a difference? Why or why not.



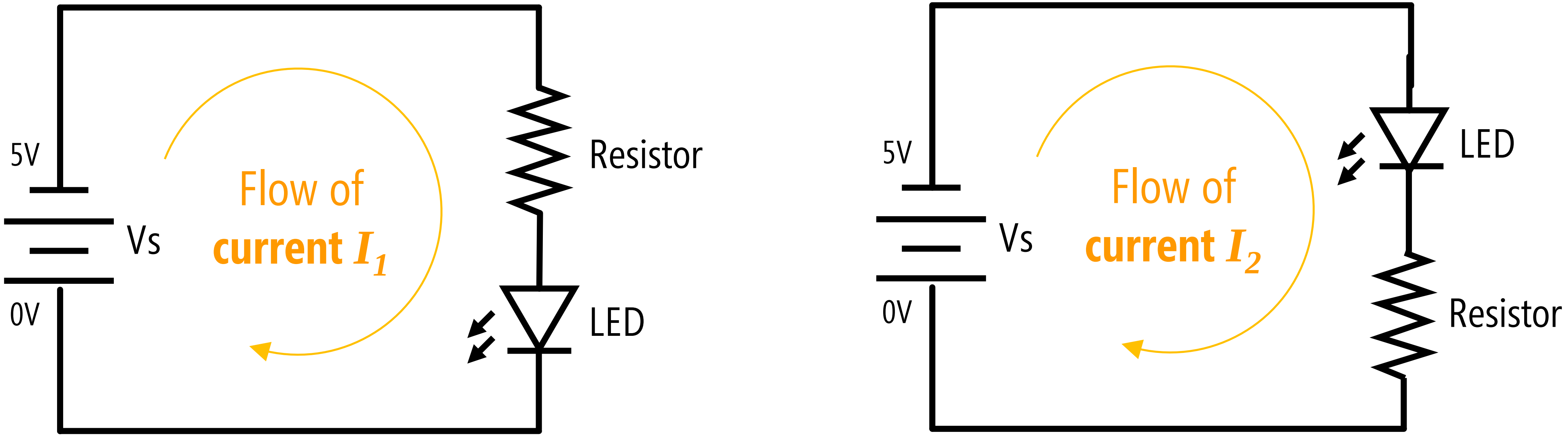


CIRCUITS

WHAT'S THE DIFFERENCE?

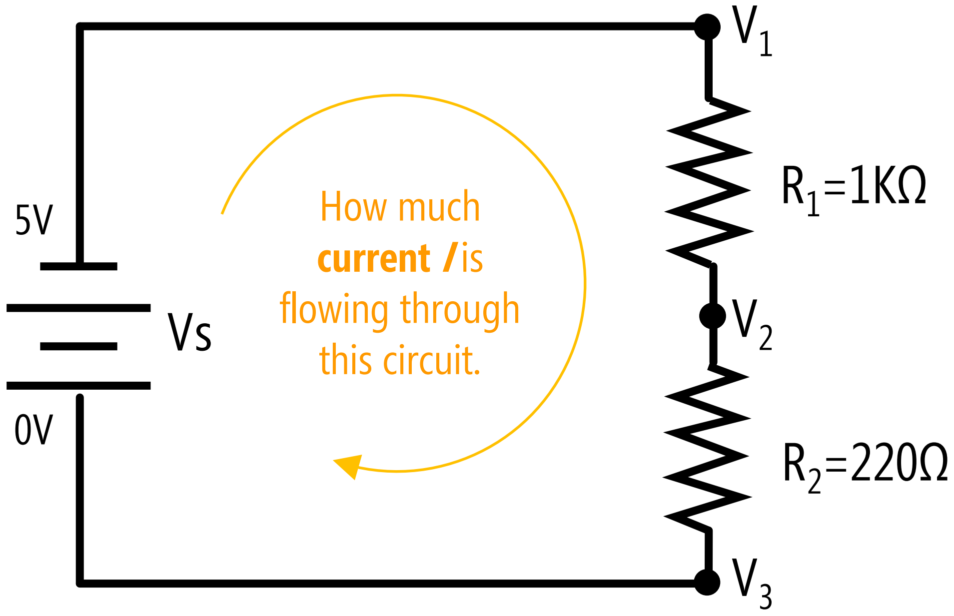
Can we put a current limiting resistor after the LED instead of before in this circuit?

Yes! There is no difference. $\mathbf{I_1} = \mathbf{I_2}$. Why? Think about Ohm's Law.
The same current flows through all components in a series circuit.



OHM'S LAW EXERCISE: RESISTORS IN SERIES

We sum resistors in series. Solve for current.



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

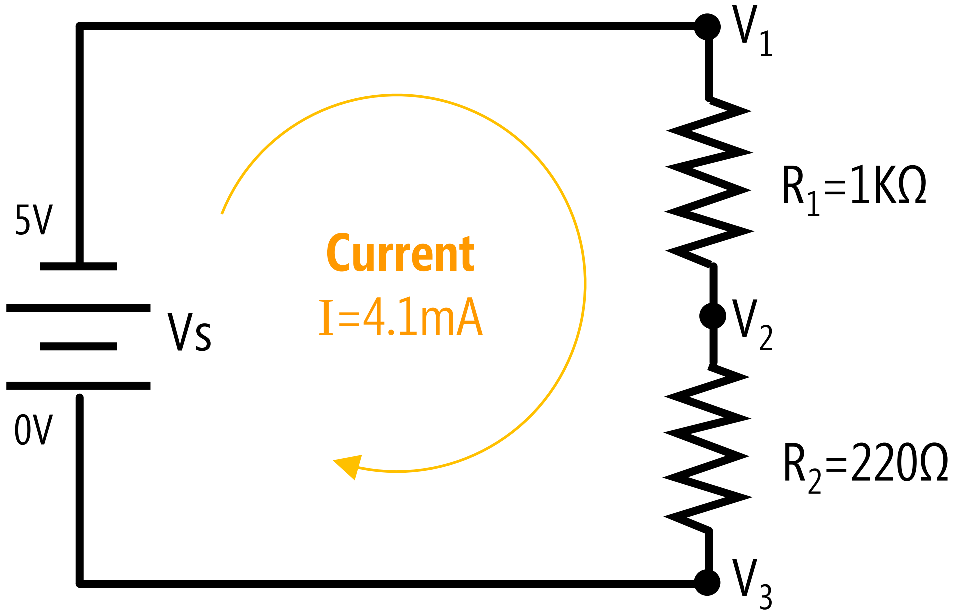
$$Current = I = \frac{V_{high\ potential} - V_{low\ potential}}{R_1 + R_2}$$

$$Current = I = \frac{5V - 0V}{1{,}000\Omega + 220\Omega}$$

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

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

How would you calculate the voltage drop over R_1?



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

$$V_1 - V_2 = I * R_1$$

$$V_2 = V_1 - I * R_1$$

And we know V_1=5V, I=4.1mA, & R_1=1KΩ

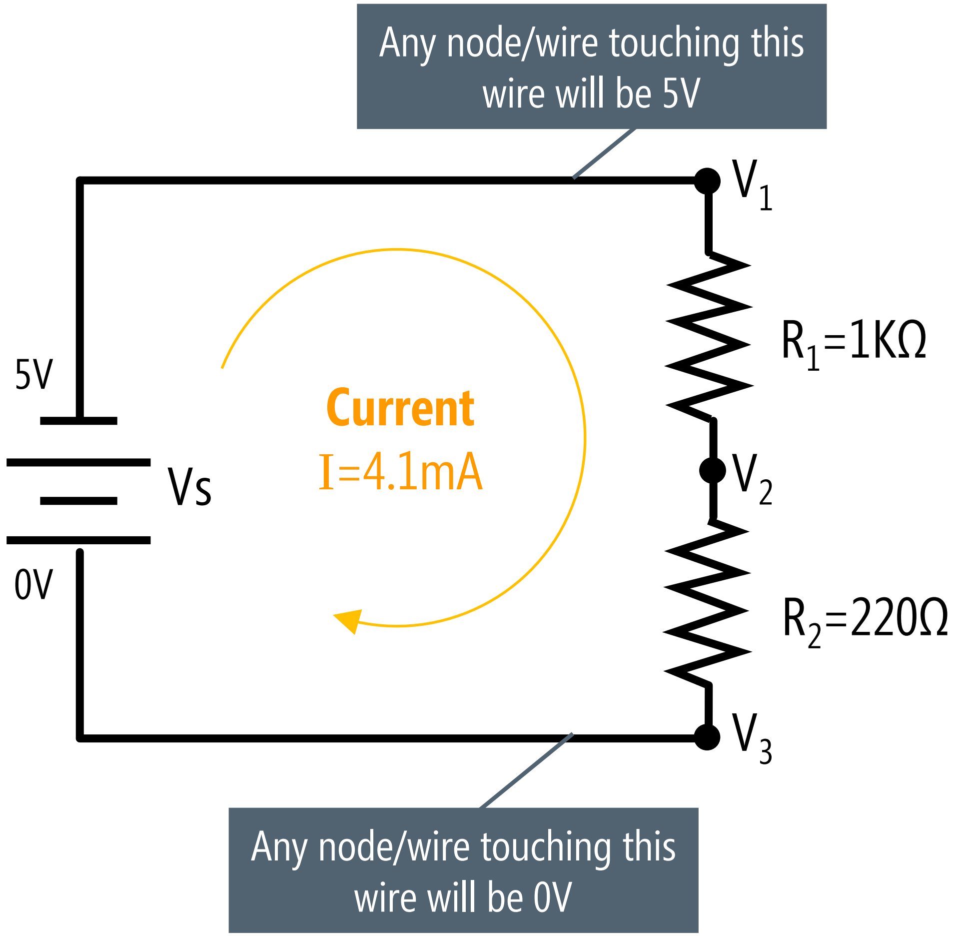
$$V_2 = 5V - 0.0041A * 1{,}000\Omega = 0.9\text{V}$$

$$V_3 = 0V$$

SERIES VS. PARALLEL RESISTANCE

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

How did I know V1 and V3?



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

$$V_1 - V_2 = I * R_1$$

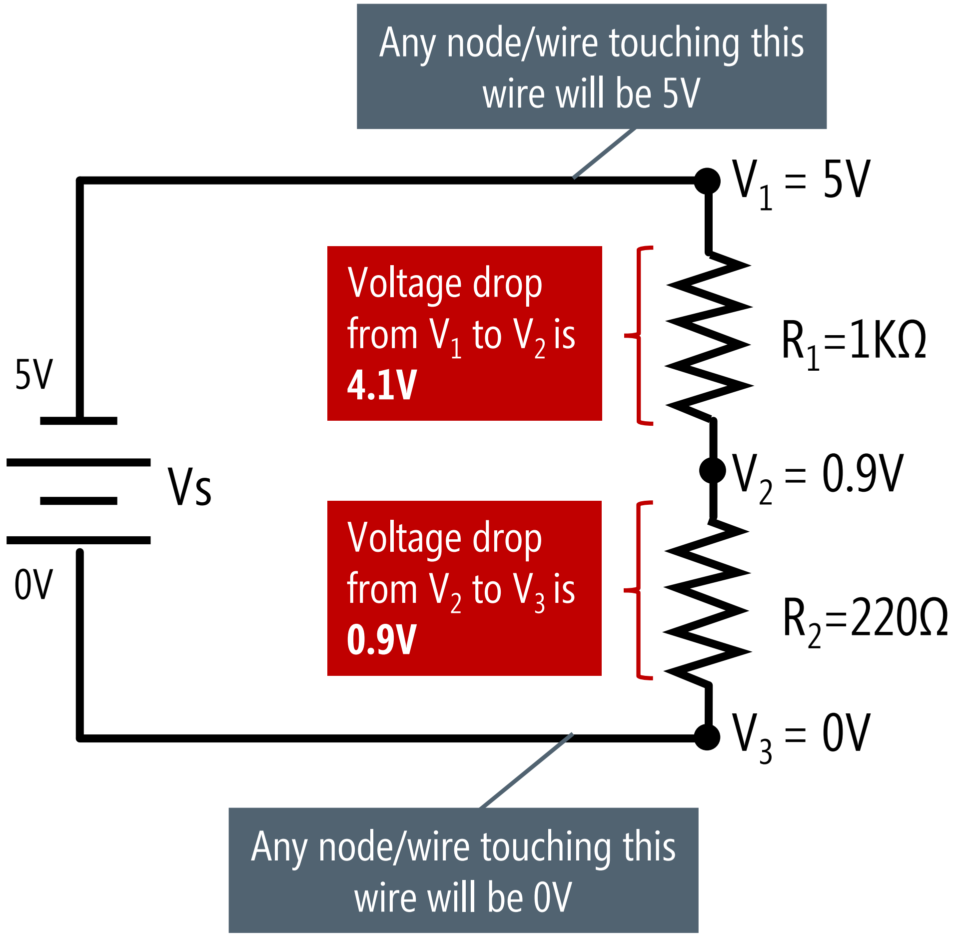
$$V_2 = V_1 - I * R_1$$ And we know V_1=5V, I=4.1mA, & R_1=1KΩ

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

$$V_3 = 0V$$

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

How did I know V1 and V3?



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

$$V_1 - V_2 = I * R_1$$

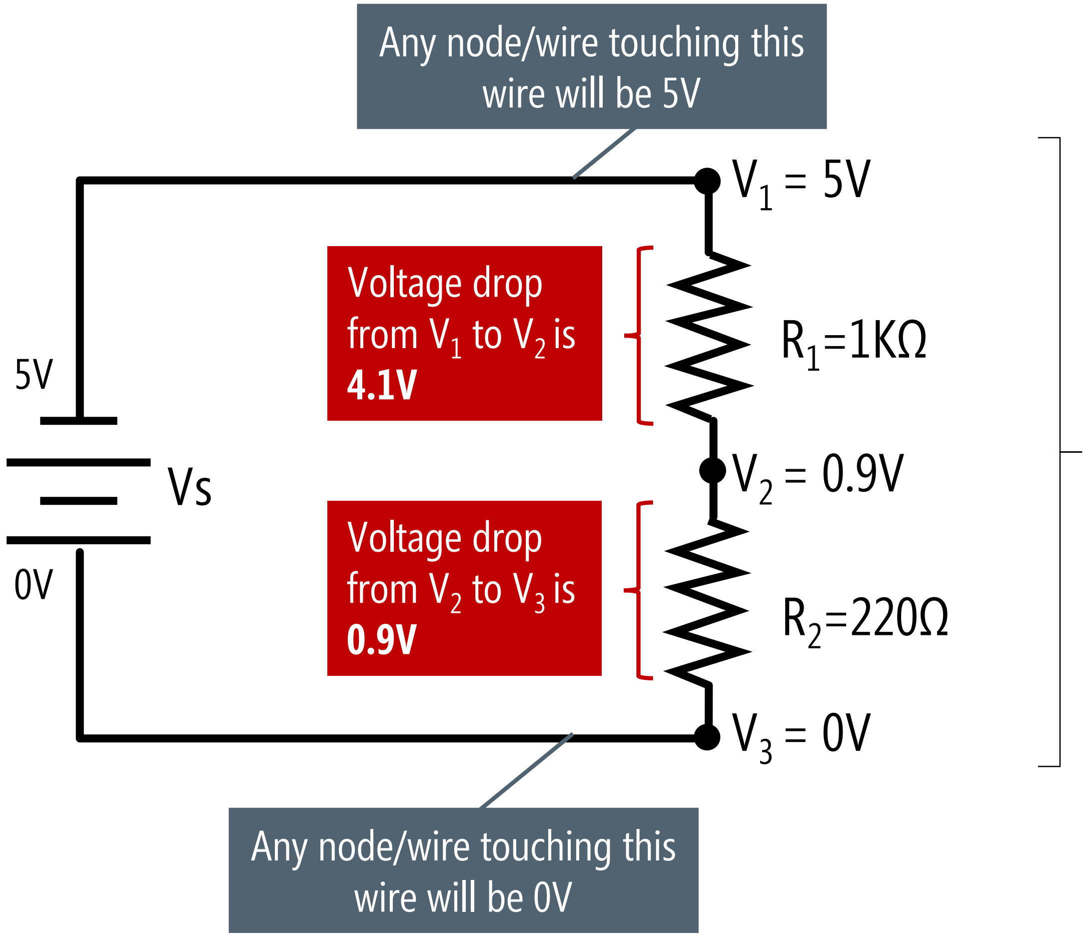
$$V_2 = V_1 - I * R_1$$ And we know V_1=5V, I=4.1mA, & R_1=1KΩ

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

$$V_3 = 0V$$

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

How did I know V1 and V3?



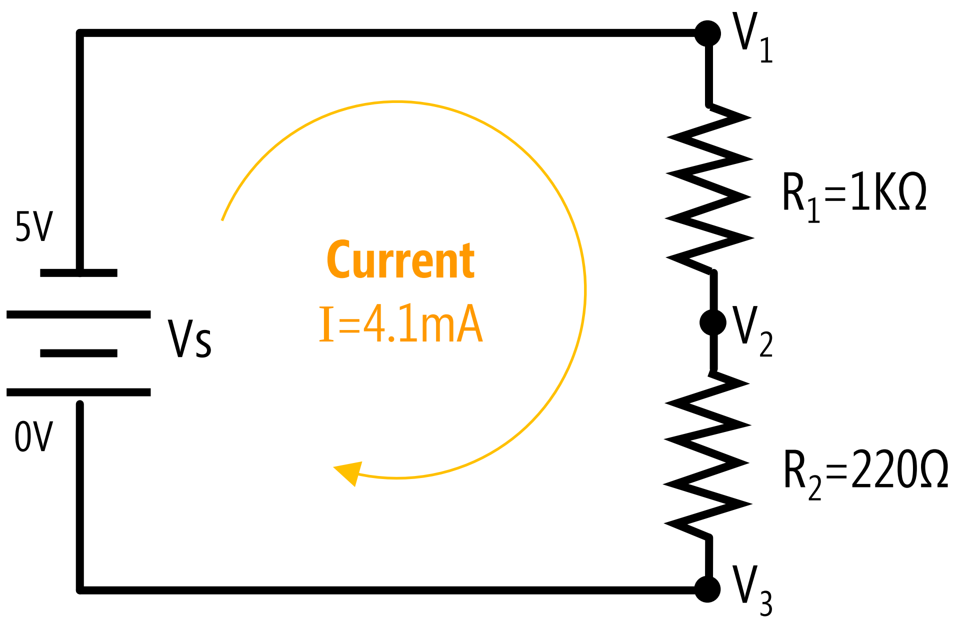
This basic circuit is called a **voltage divider** because it "splits" or "divides" voltages across nodes.

It is one of the **most common** (and useful) circuit configurations when working with microcontrollers

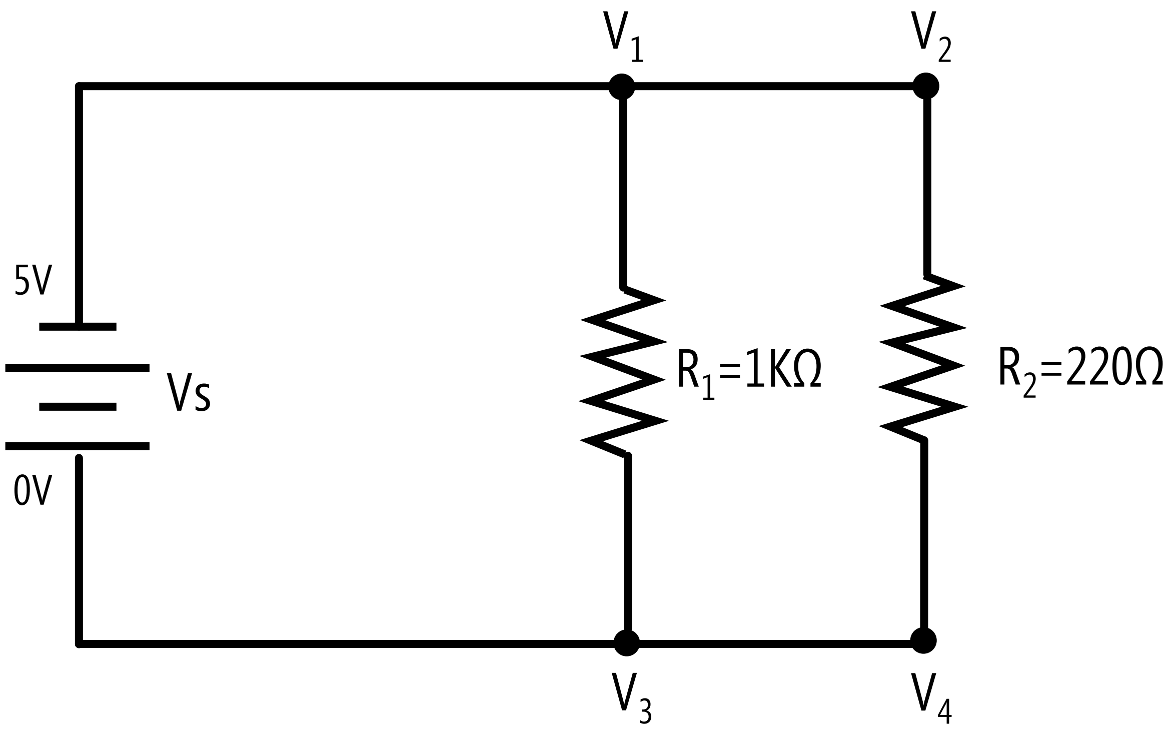
SERIES VS. PARALLEL RESISTANCE

BUT WHAT ABOUT RESISTORS IN PARALLEL?

Resistors in Series

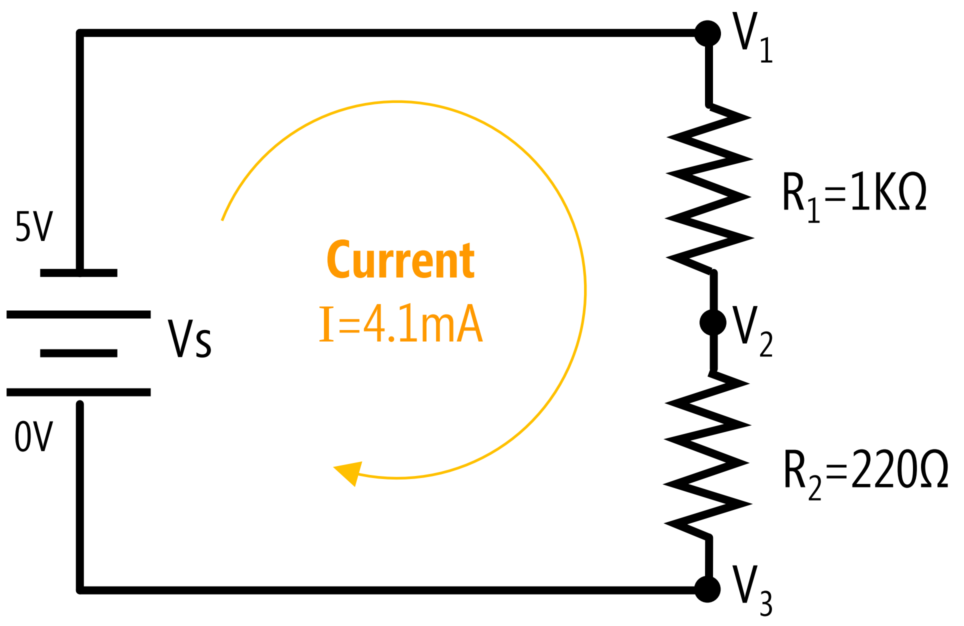


Resistors in Parallel

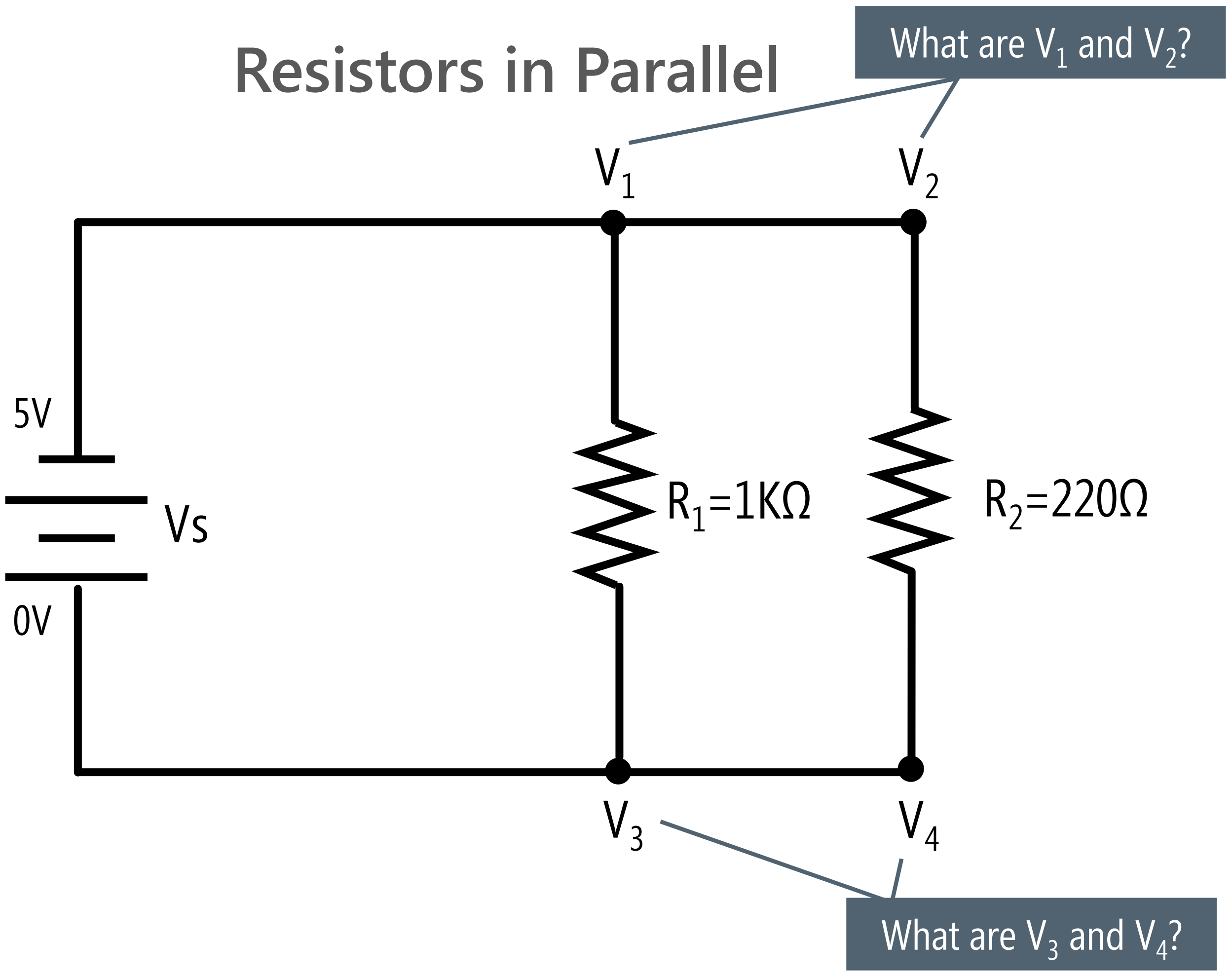


WHAT ARE V1, V2, V3 AND V4?

Resistors in Series

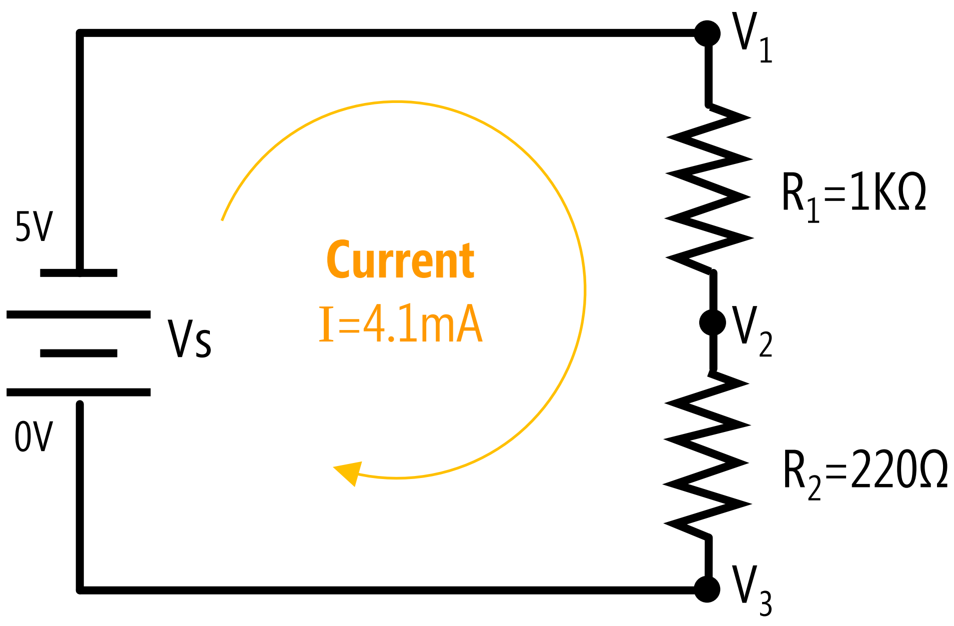


Resistors in Parallel

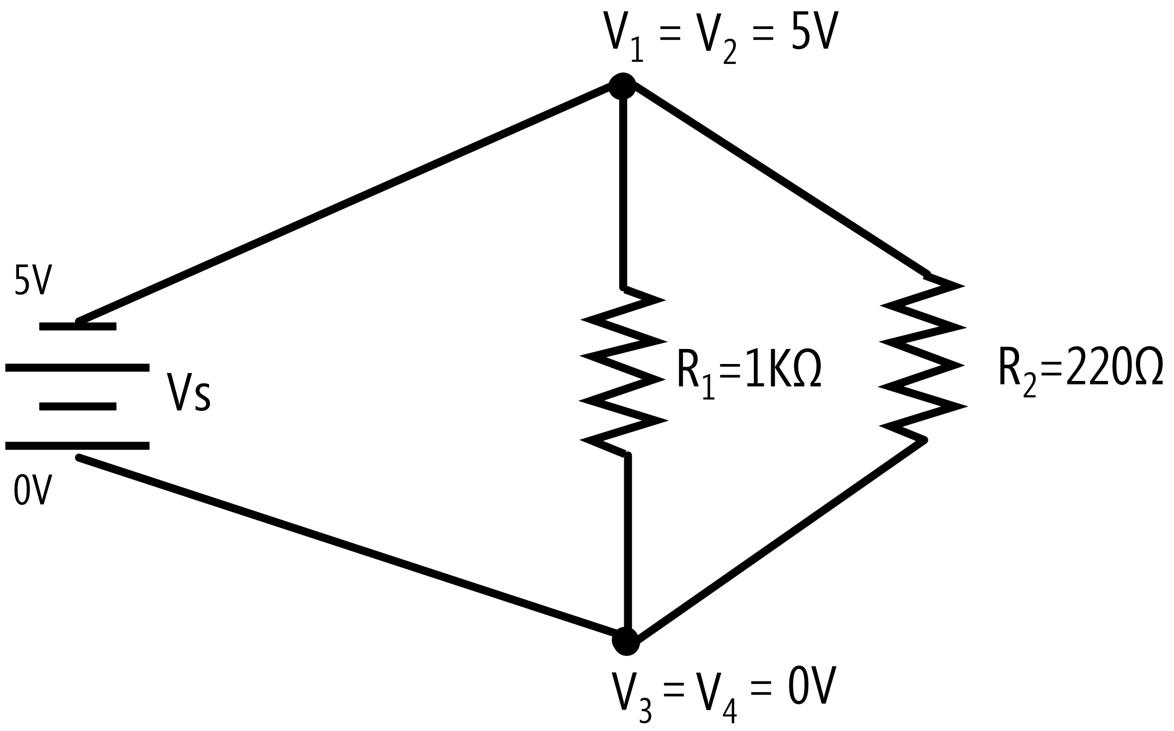


SOMETIMES IT HELPS TO DRAW THE CIRCUIT…

Resistors in Series



Resistors in Parallel

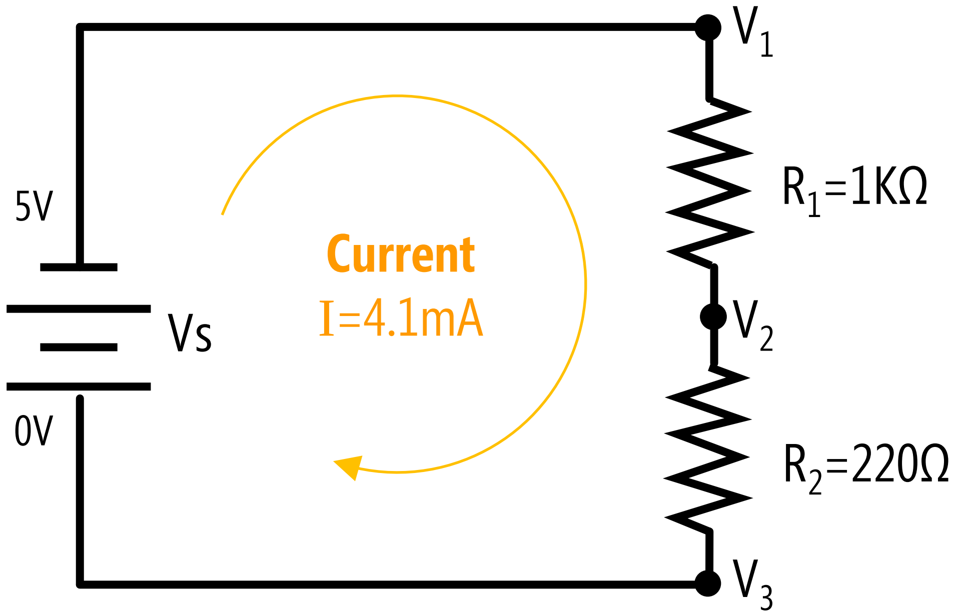


For more, see: https://learn.sparkfun.com/tutorials/series-and-parallel-circuits

RESISTORS IN PARALLEL SPLIT THE CURRENT

Resistors in Series

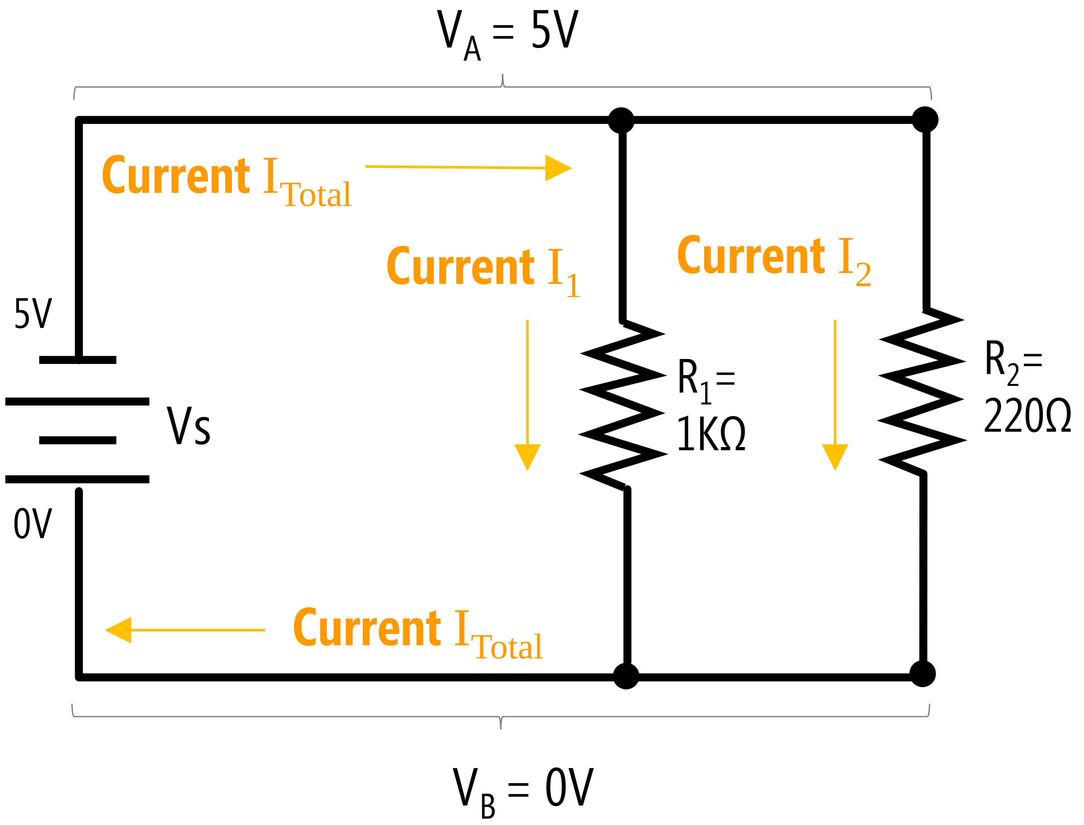
Voltage Divider



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

Resistors in Parallel

Current Divider

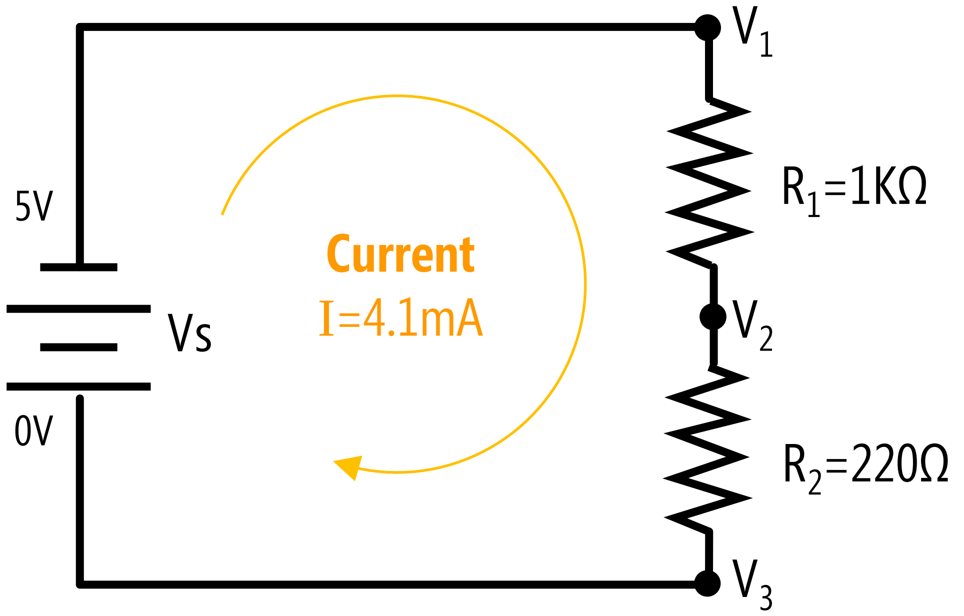


Here, there are **two** potential branches for current to flow. The amount of current across each branch is **dependent** on the **resistance** values.

SERIES VS. PARALLEL RESISTANCE

WHICH BRANCH HAS MORE CURRENT?

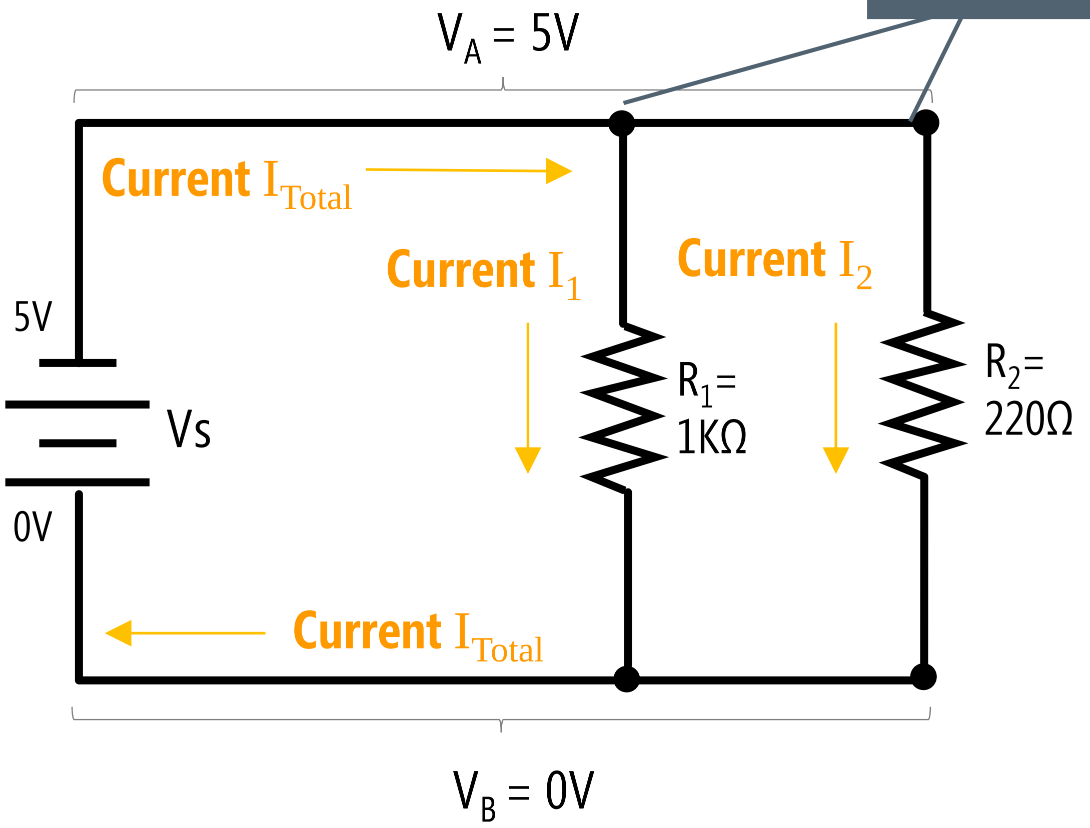
Resistors in Series



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

Resistors in Parallel

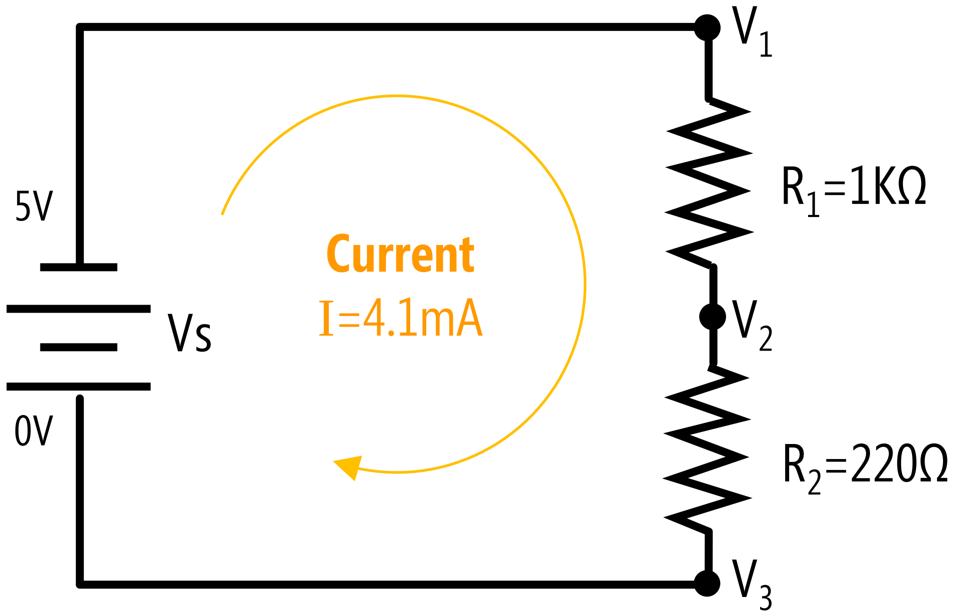
Which branch has more **current**? I_1 or I_2



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

REMEMBER OUR WATER ANALOGY… AND OHM'S LAW

Resistors in Series



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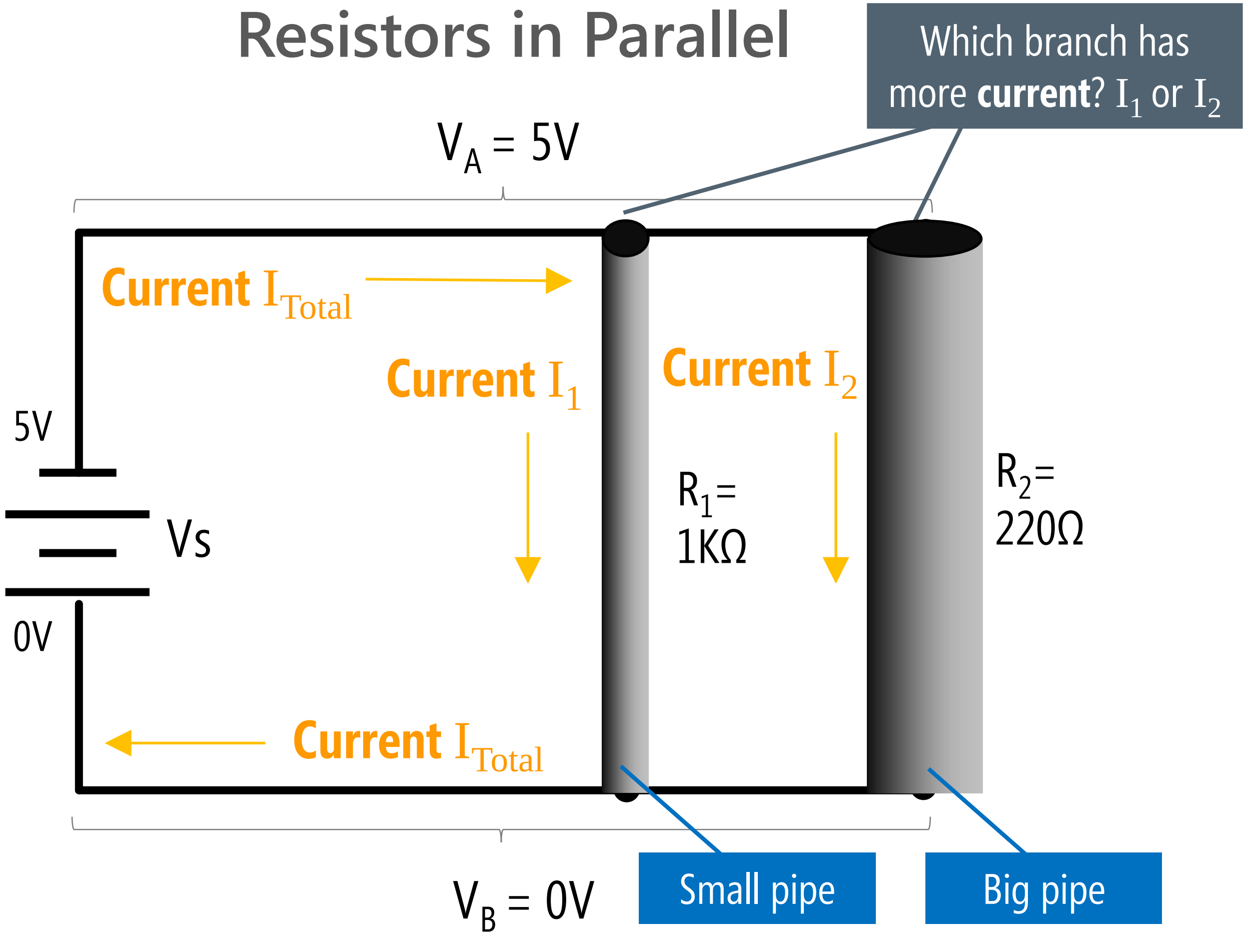
Resistors in Parallel



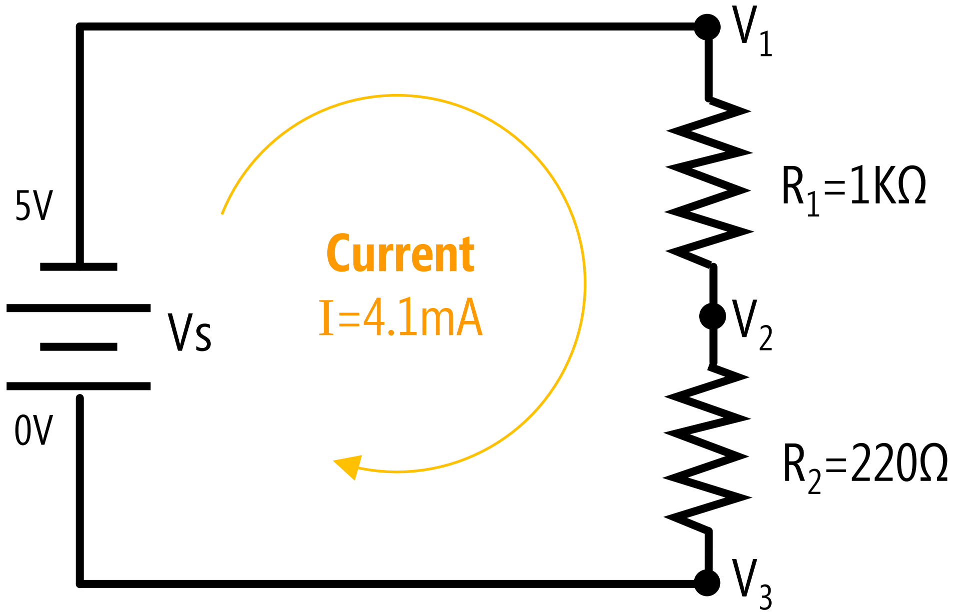
Here, there are **two** potential branches for current to flow. The amount of current across each branch is **dependent** on the **resistance** values.

SERIES VS. PARALLEL RESISTANCE

SOLVE FOR I_1 AND I_2

We expect I_1 to be bigger than I_2

Resistors in Series

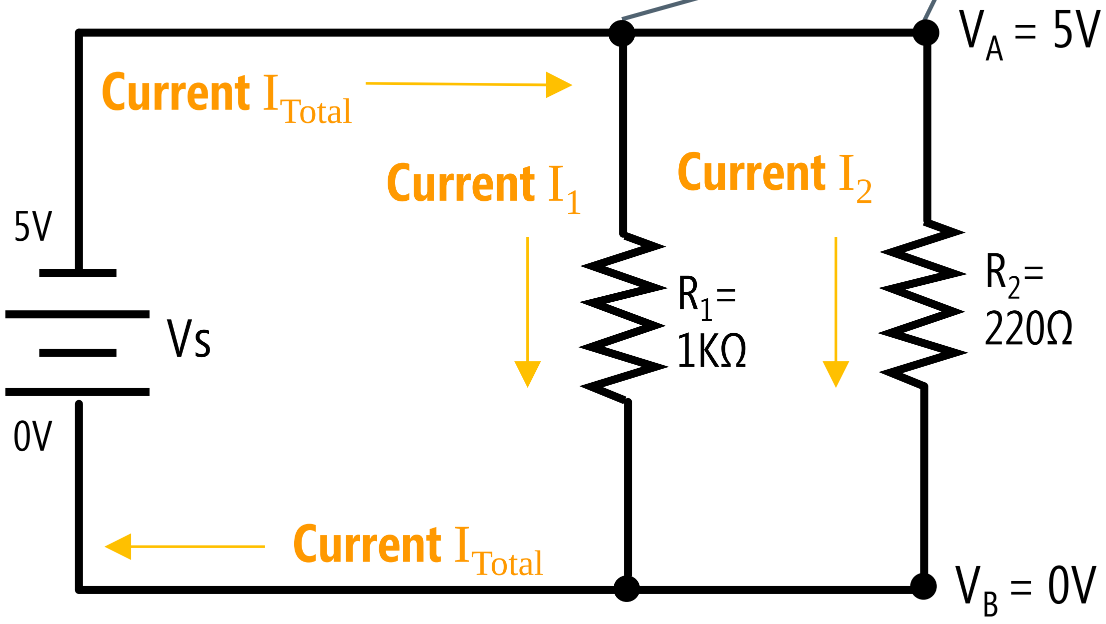


$$Current = I = \frac{V_{high\ potential} - V_{low\ potential}}{R_1 + R_2}$$

$$Current = I = \frac{5V - 0V}{1{,}000\Omega + 220\Omega}$$

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

Resistors in Parallel



$$I_1 = \frac{V_A - V_B}{R_1}$$

$$I_1 = \frac{5V - 0V}{1{,}000\Omega}$$

$$I_1 = 0.005A = 5mA$$

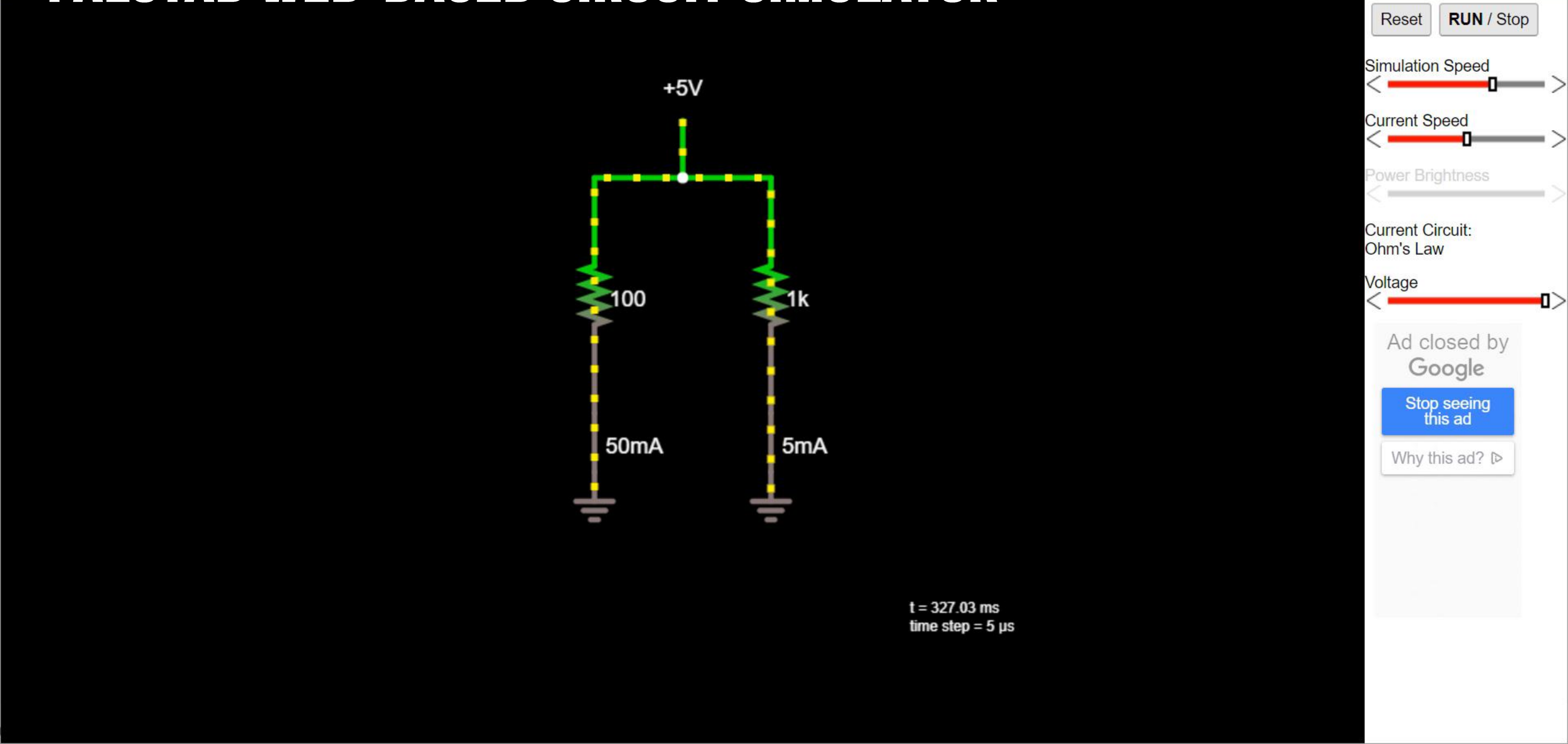
$$I_2 = \frac{V_A - V_B}{R_2}$$

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

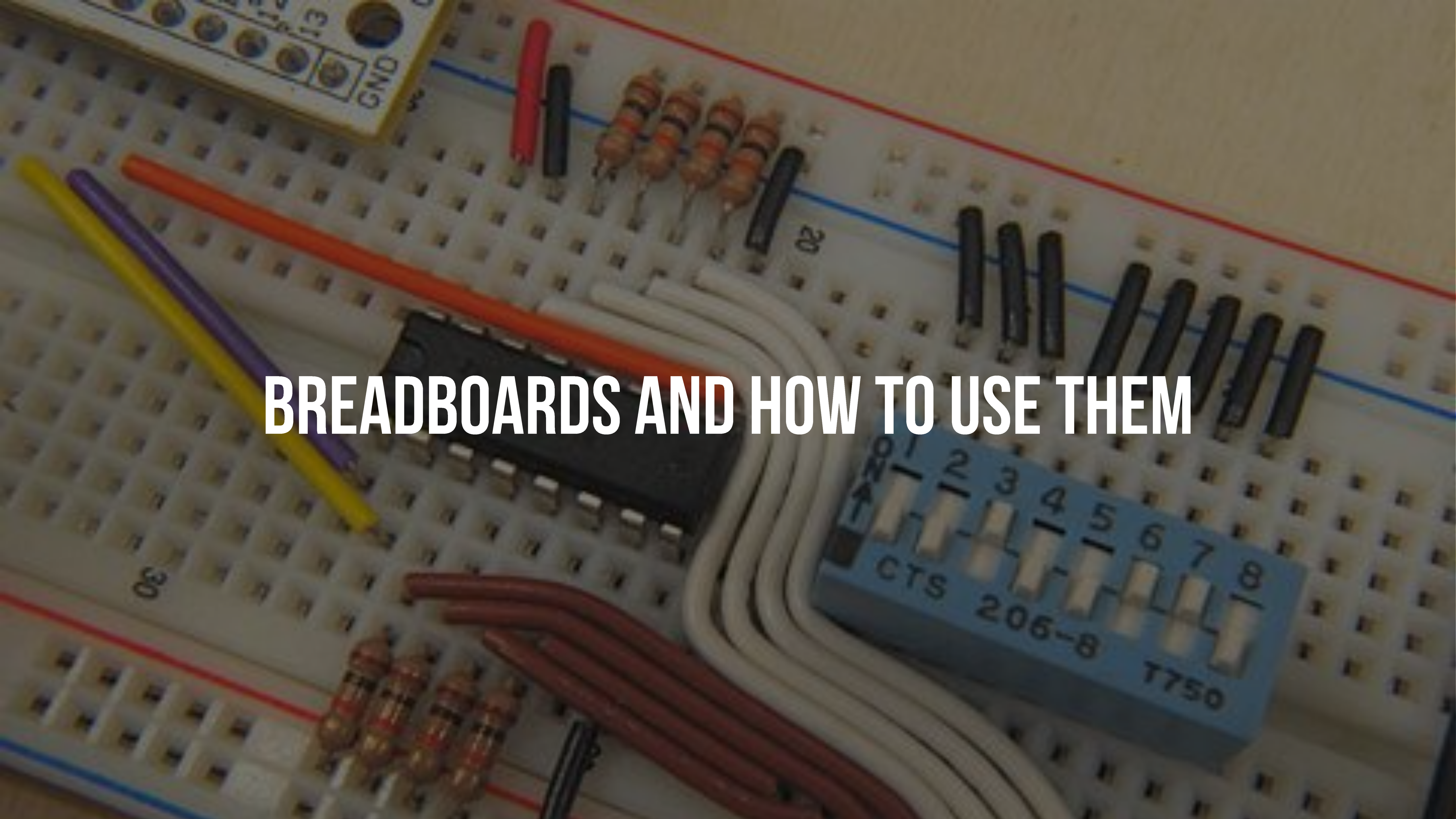
$$I_2 = 0.0227A = 22.7mA$$

CIRCUITS

FALSTAD WEB-BASED CIRCUIT SIMULATOR



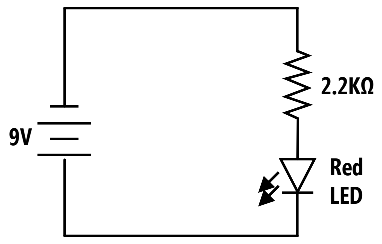
BREADBOARDS AND HOW TO USE THEM

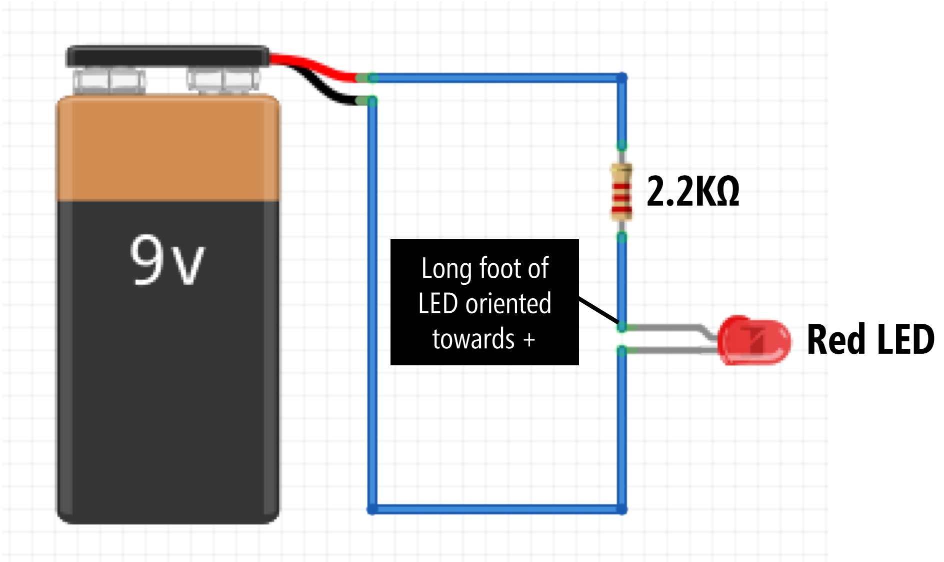


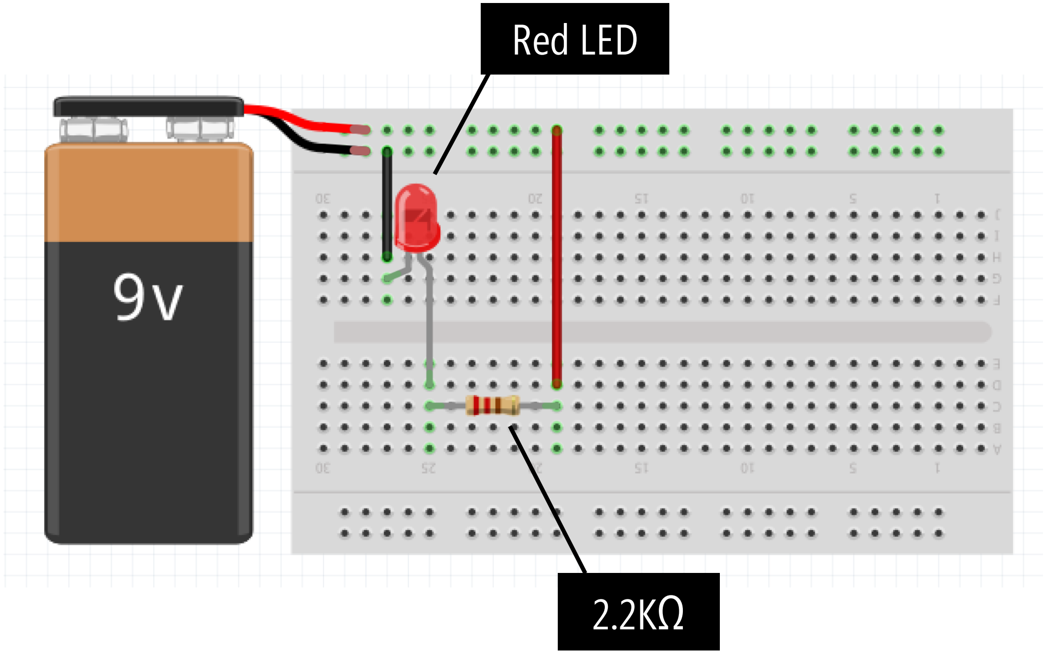
ACTIVITY

ADAPT YOUR CIRCUIT TO USE A BREADBOARD

This is the same circuit as before but now we'll use a breadboard! ☺







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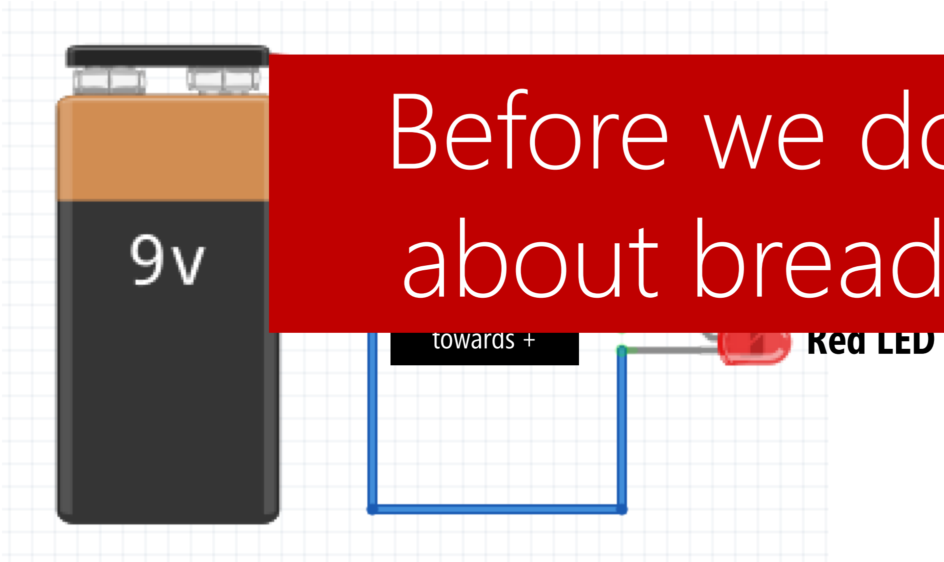
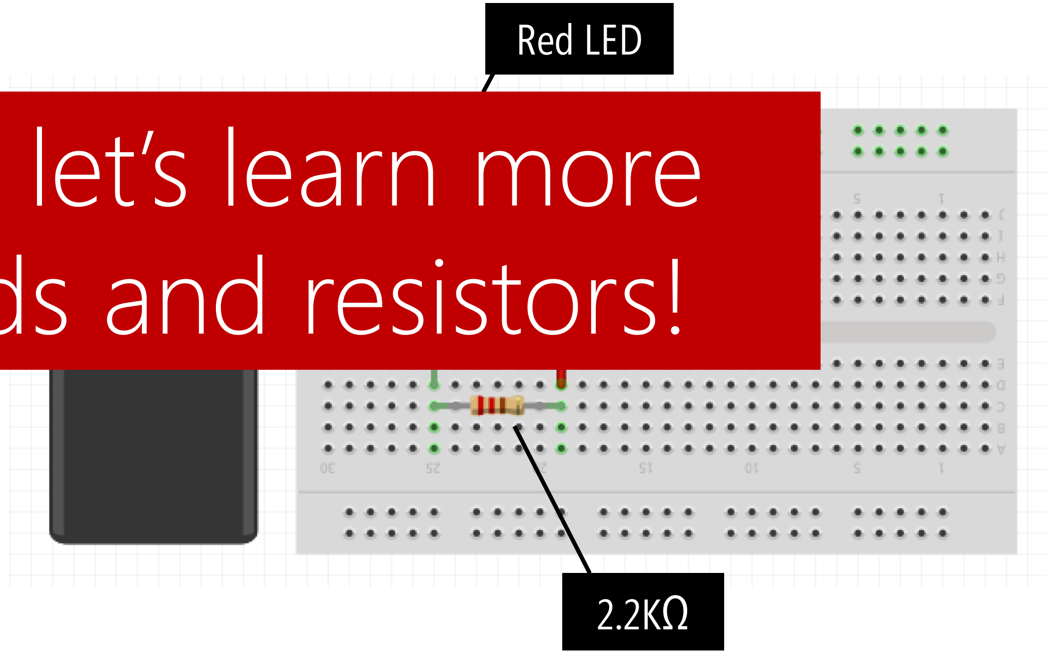
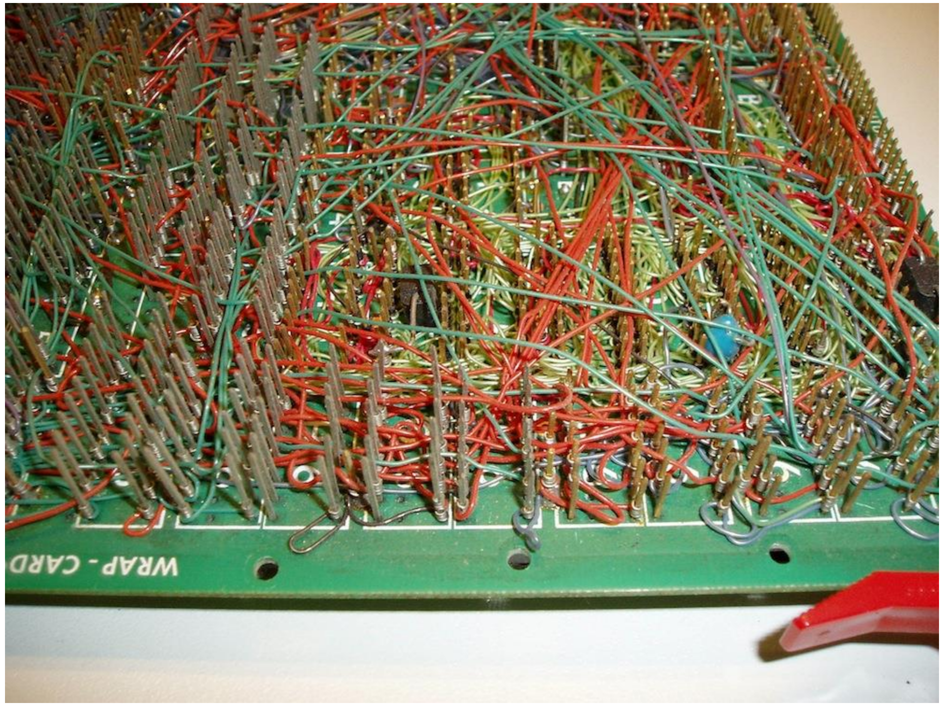




Before we do this, let's learn more about breadboards and resistors!

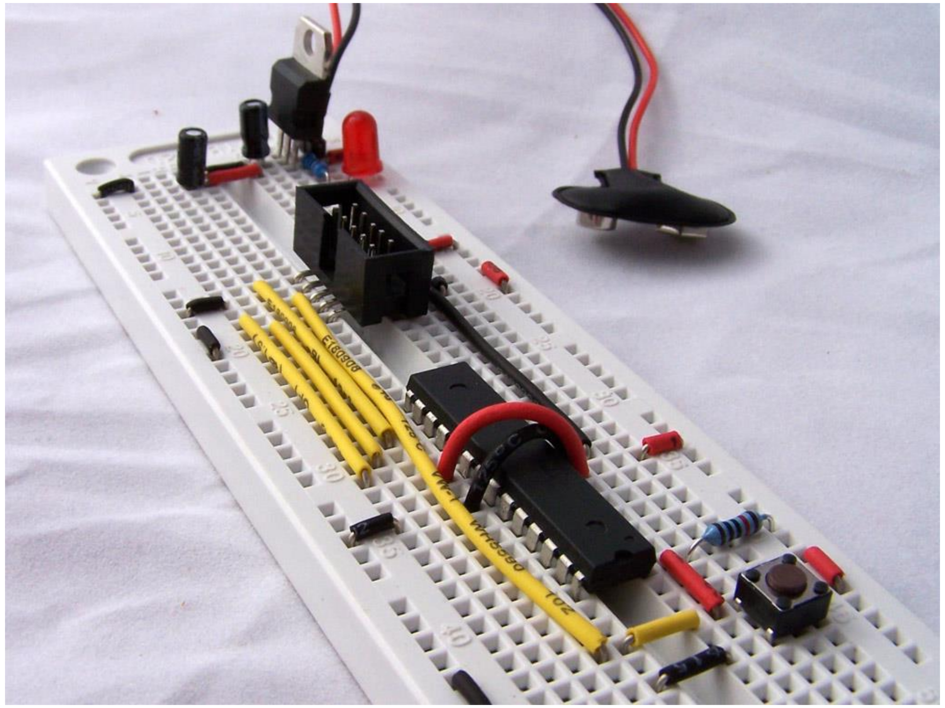
WHAT IS A BREADBOARD?

Breadboards are quick way of wiring and prototyping circuits



WIRE WRAPPING CIRCA ~1960

Wire wrapping involved wrapping wires around conductive posts attached to perfboards



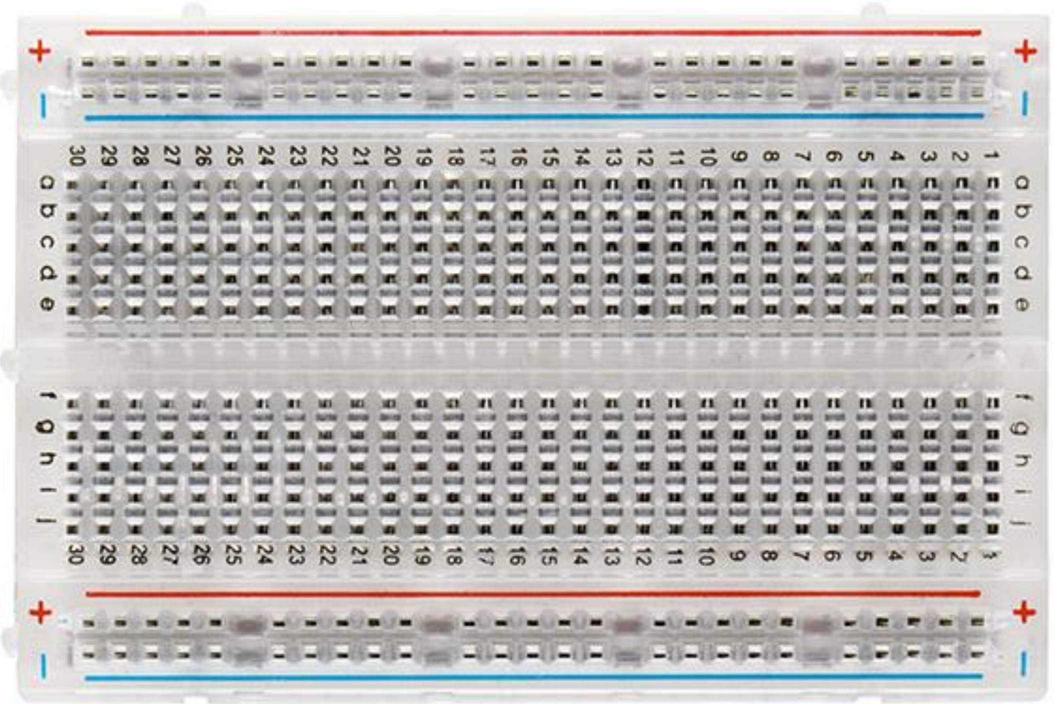
BREADBOARDING

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

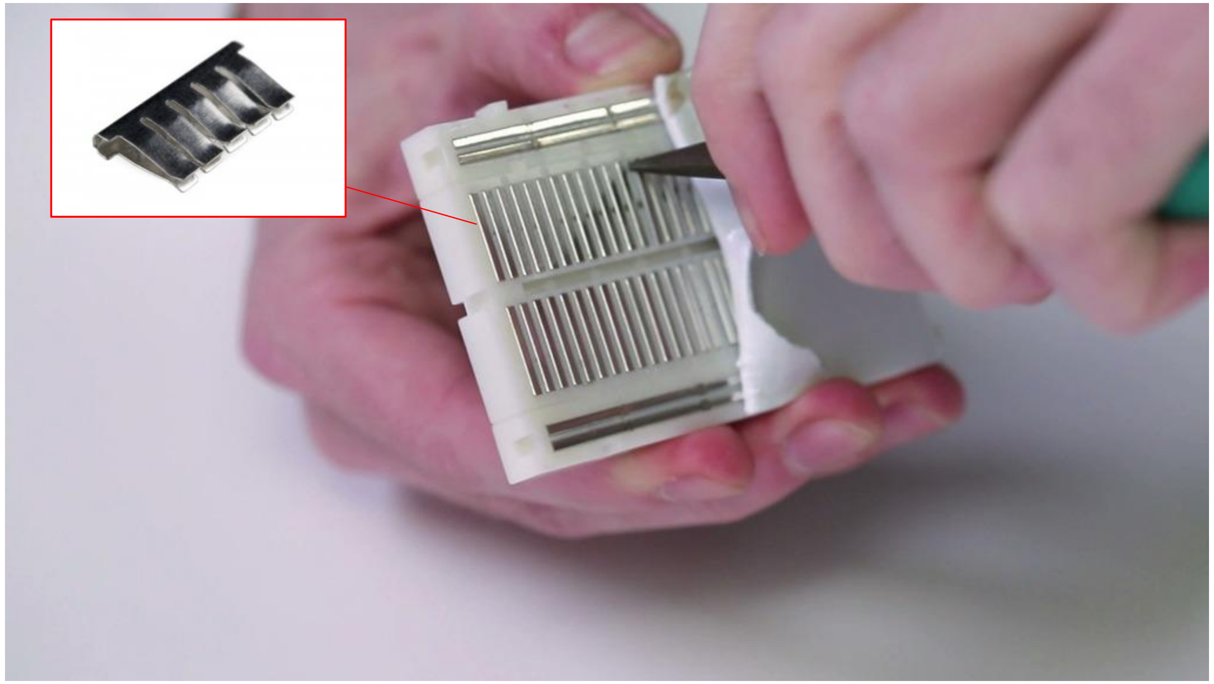
Source: https://learn.sparkfun.com/tutorials/how-to-use-a-breadboard

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)

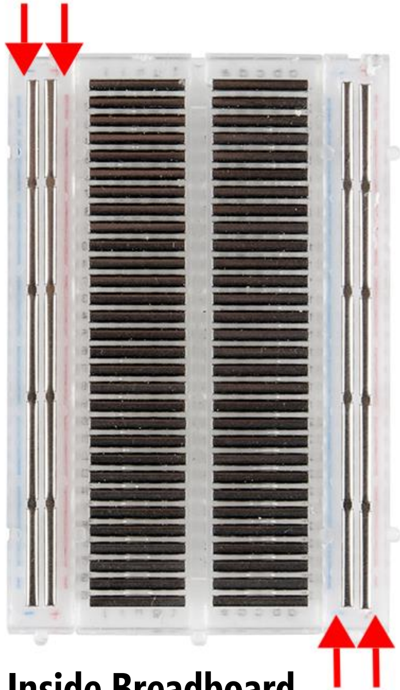
ROW SET 1
Each row wired together

COLUMN SET 1
Each column wired together

COLUMN SET 2
Each column wired together

ROW SET 2
Each row wired together

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



Inside Breadboard
Viewed from the bottom

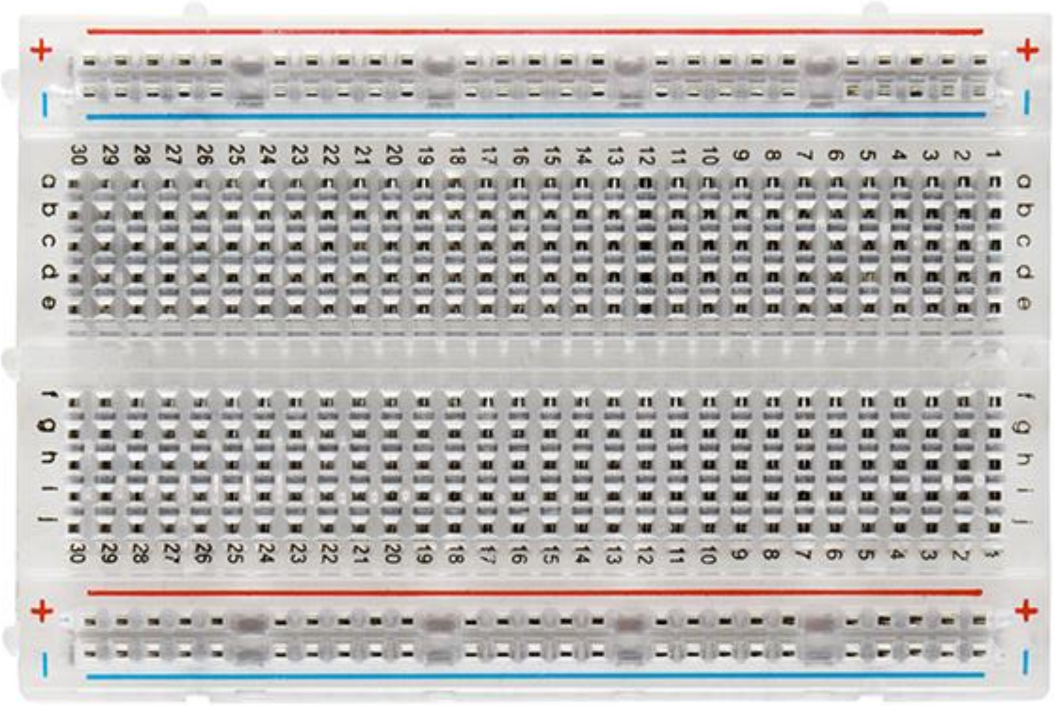
BREADBOARD TIP 1: USE RAILS FOR VOLTAGE SUPPLY & GROUND

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



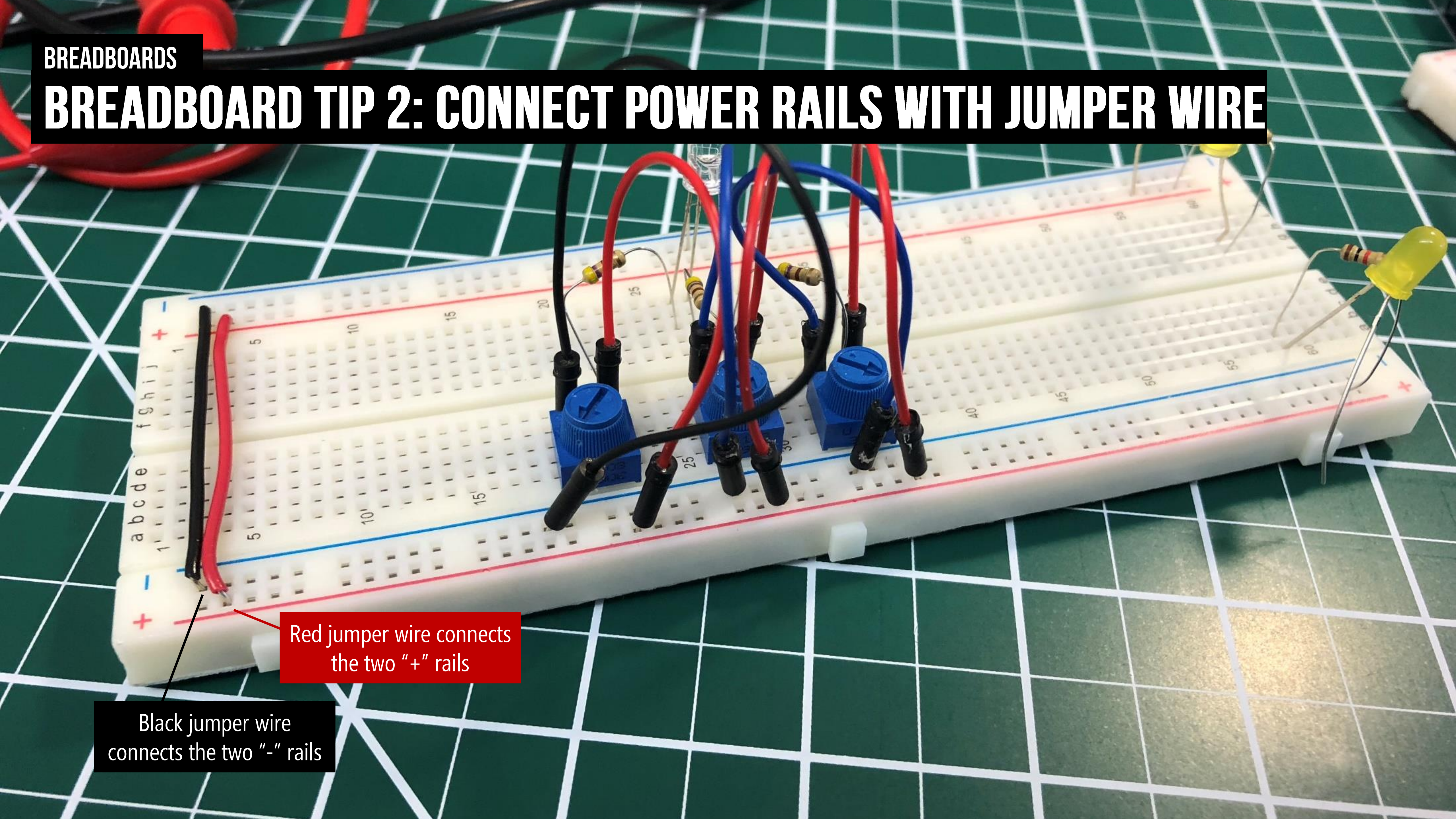
Typically we hook up **Vs** (our positive voltage source) here

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

This wiring configuration just makes things easier.

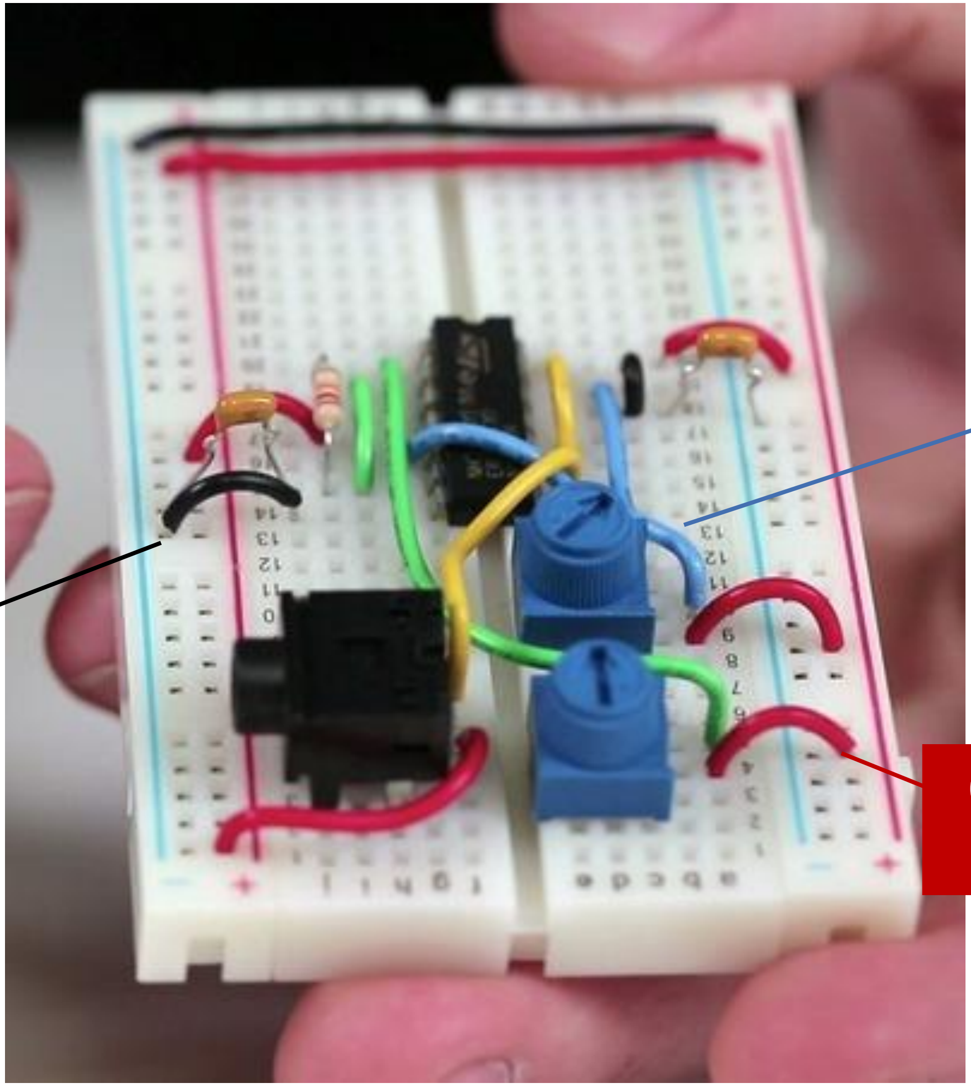
In fact, this part of the breadboard is often called "power rails"

BREADBOARD TIP 2: CONNECT POWER RAILS WITH JUMPER WIRE



BREADBOARD TIP 3: USE WIRE COLOR TO MEAN SOMETHING

Only use black wire for wires that connect to GND

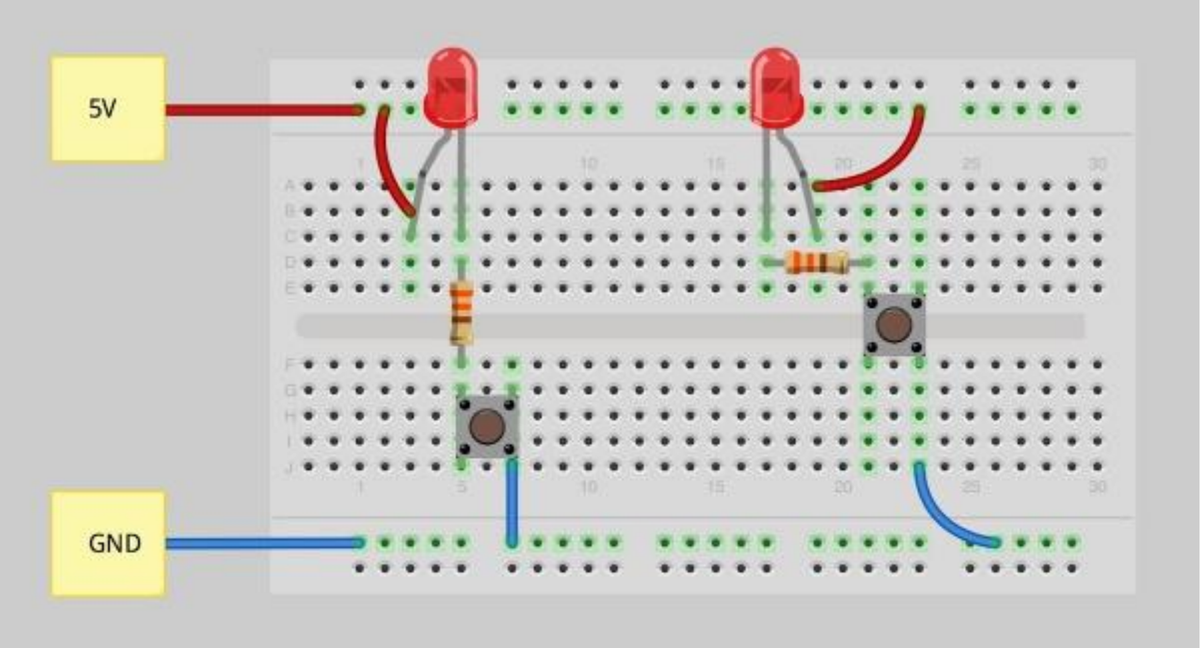


Use other wire colors to indicate other meaning

Only use red wire for wires that connect to power (or Vcc)

BREADBOARD TIP 4: 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.

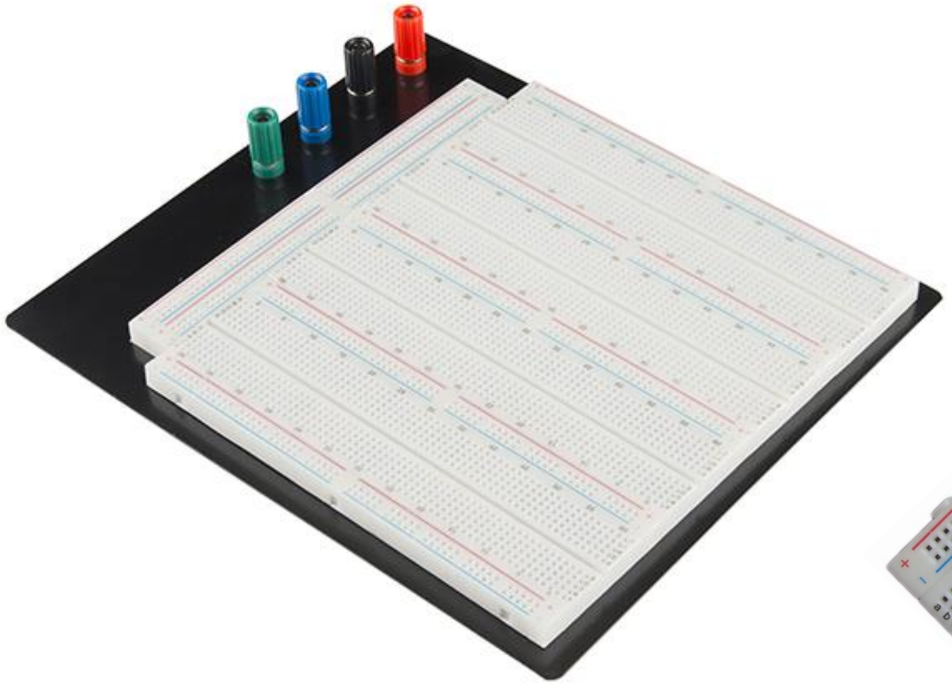


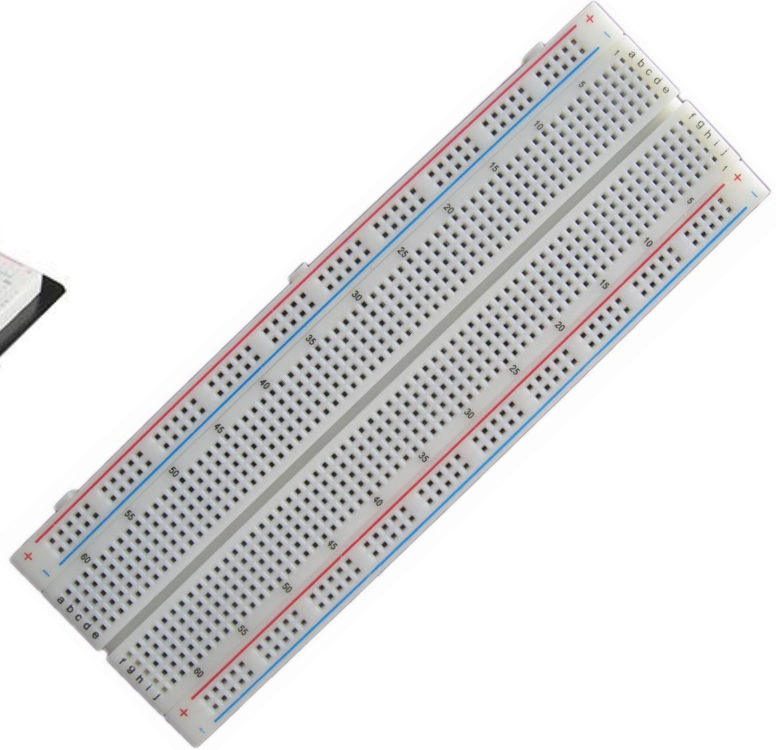
Notice how the 5V and GND rails are only connected on opposite sides of the breadboard. This is to limit stupid mistakes!

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

BREADBOARDS

LOTS OF DIFFERENT BREADBOARD SIZES





Which breadboards do you have in your Arduino kits?

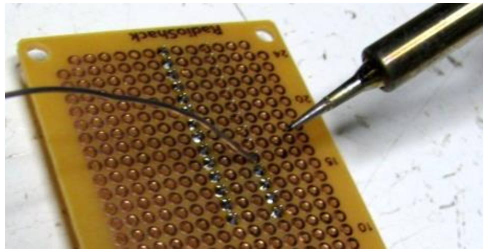
BREADBOARDS ARE LIKE LEGOS!

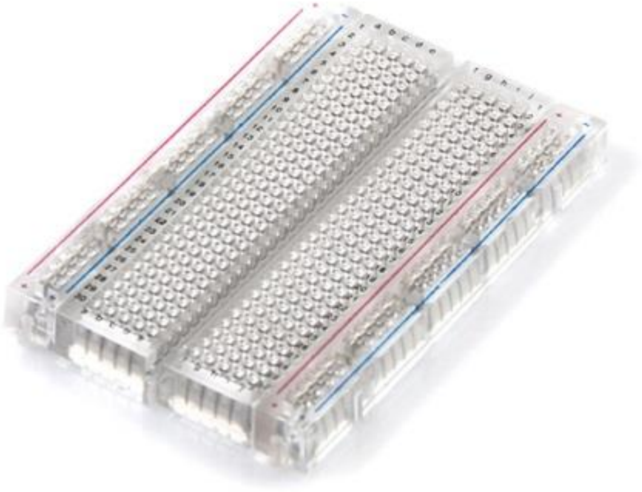
Many breadboards have little nubbins and slots on the sides, and some even have them on the tops and bottoms. These allow you to connect multiple breadboards together to form the ultimate prototyping surface.

[source: sparkfun.com]

BREADBOARDS VS. PERFBOARDS

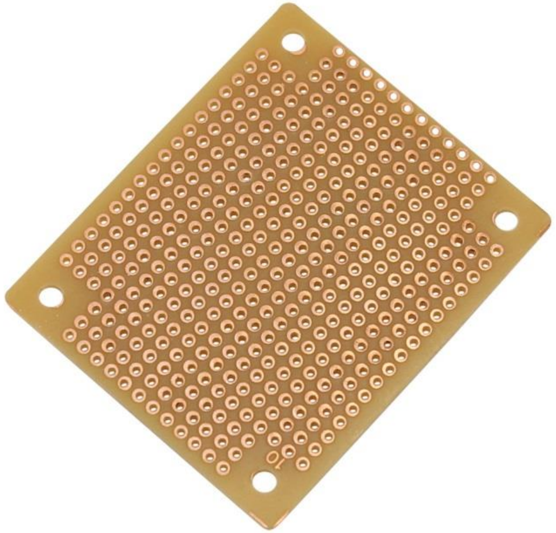
Typically, you start prototyping on a breadboard but then switch over to something like a perfboard once your design is starting to solidify or you want something more permanent. Perfboards require soldering.





Breadboard

!=

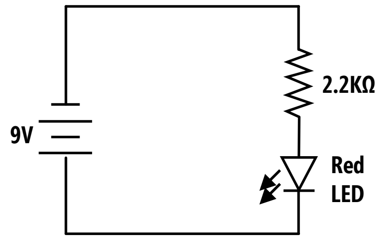


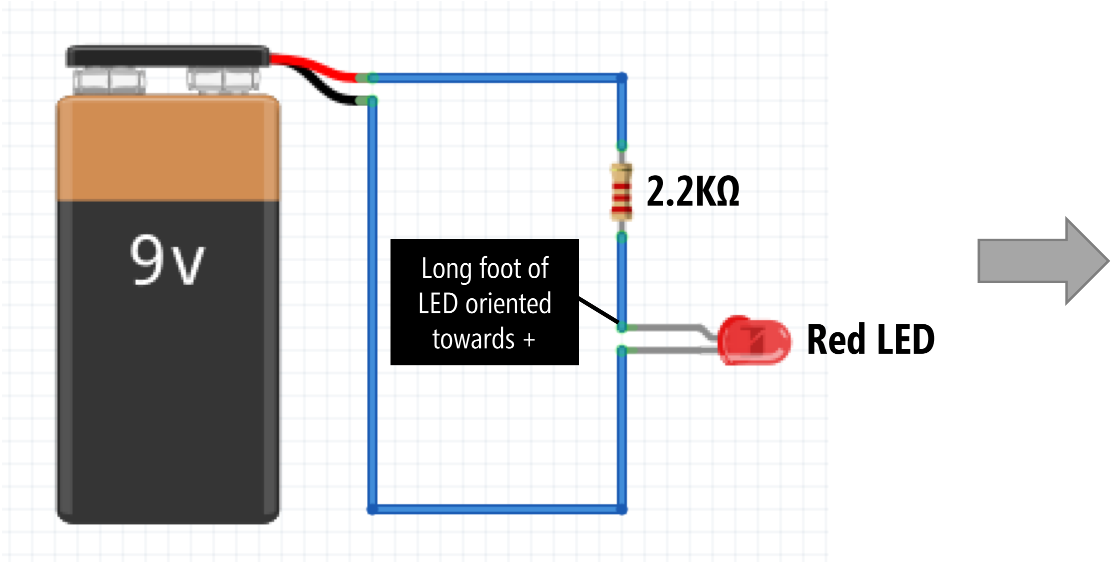
Perfboard

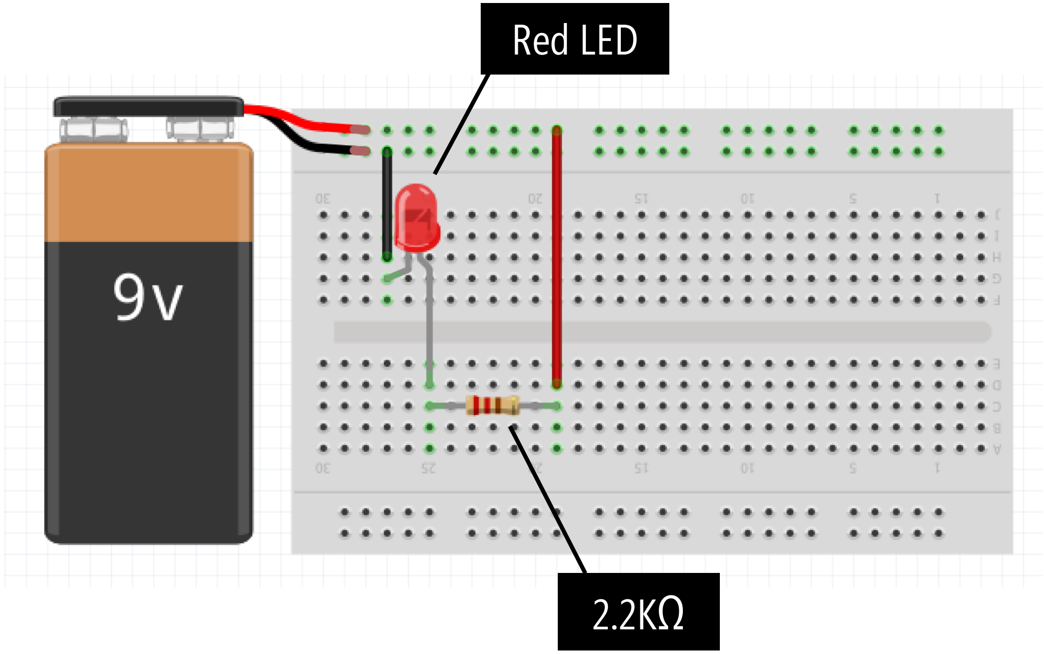
ACTIVITY

ADAPT YOUR CIRCUIT TO USE A BREADBOARD

This is the same circuit as before but now we'll use a breadboard! ☺

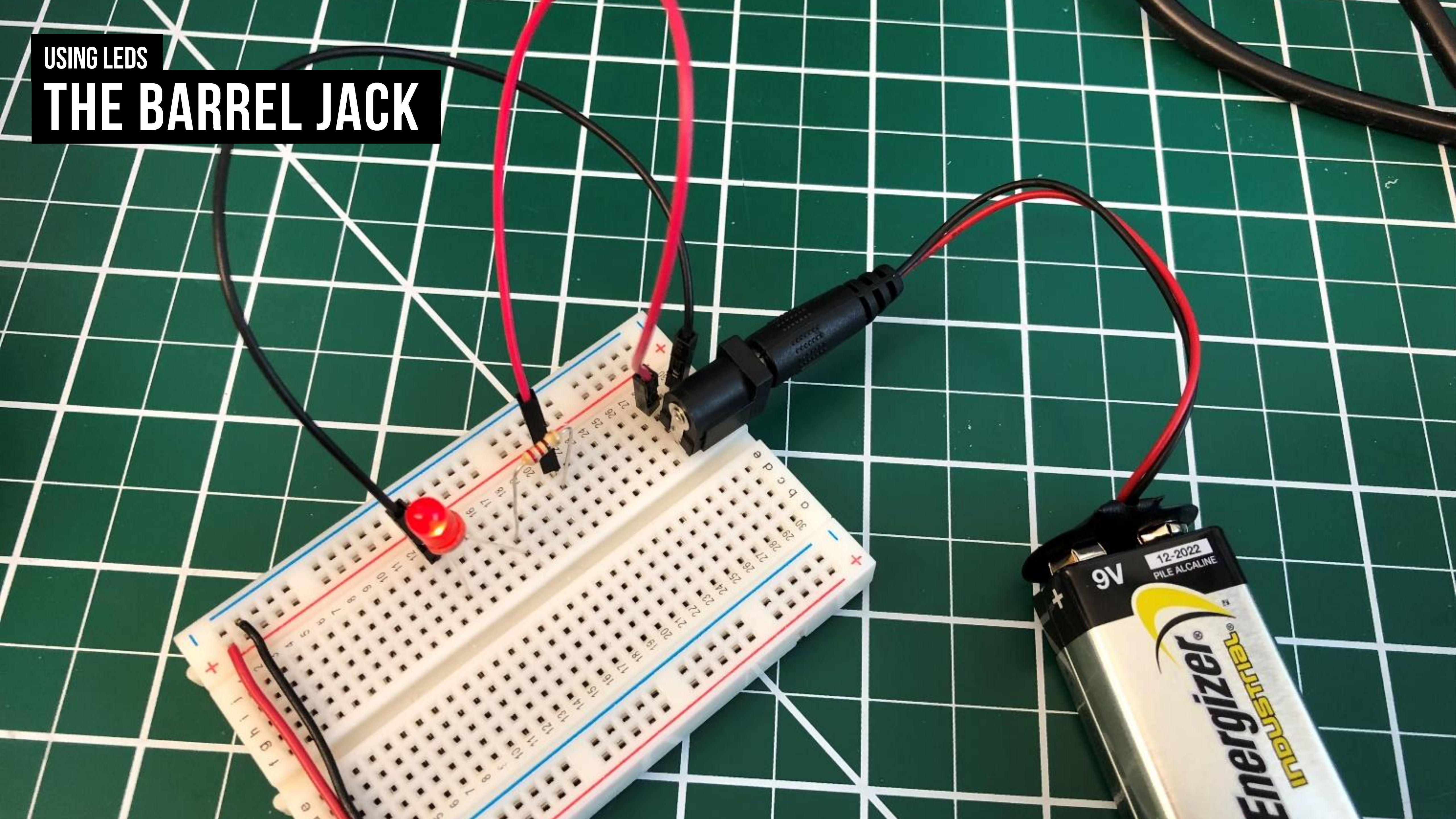






USING LEDS

THE BARREL JACK



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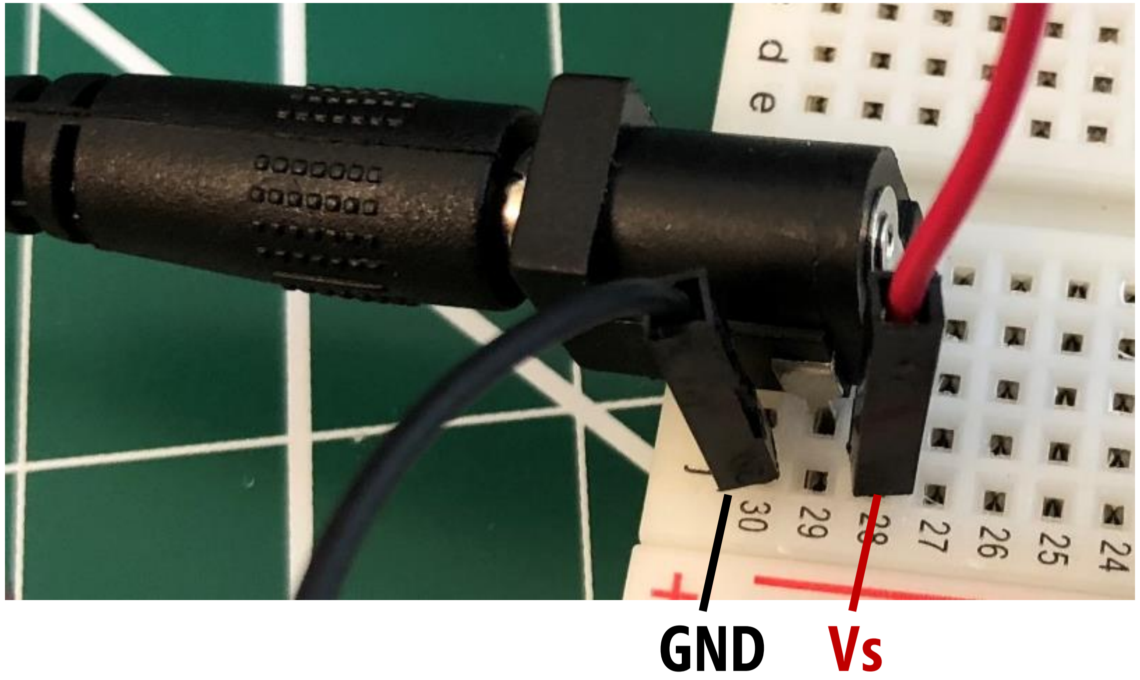
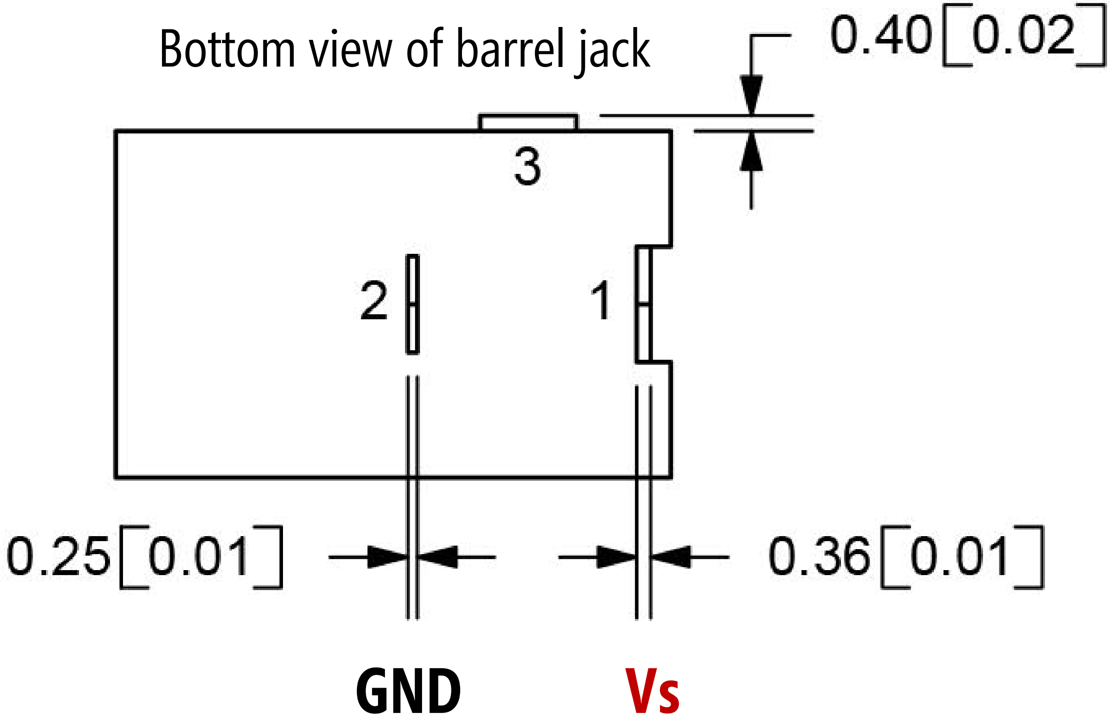
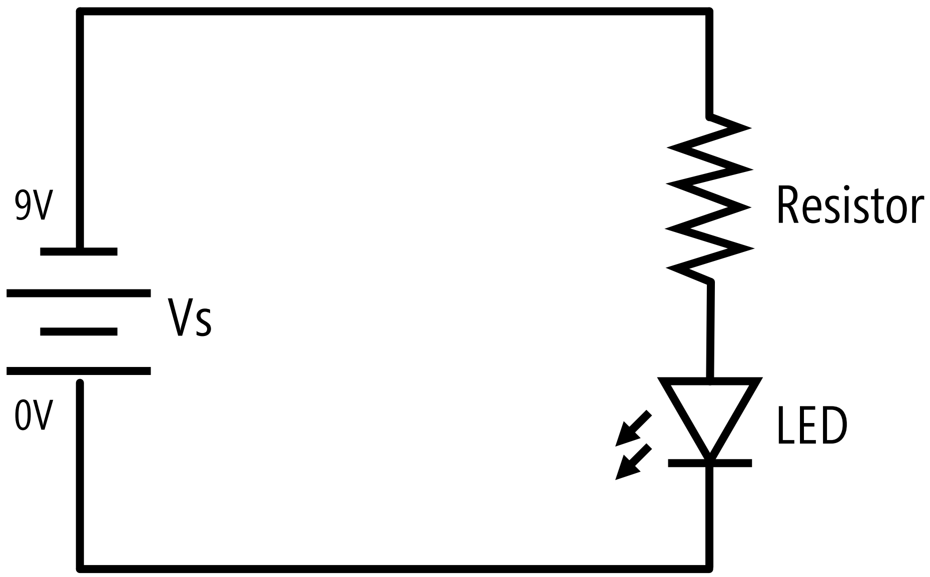




https://cdn.solarbotics.com/products/datasheets/pj-002a.pdf

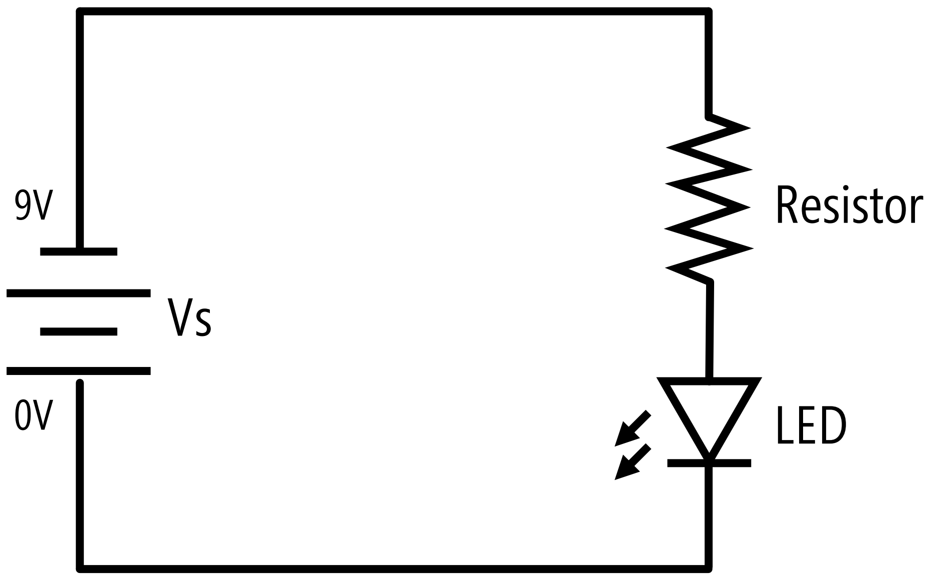
EXERCISE: LET'S HOOKUP OUR FIRST CIRCUIT!

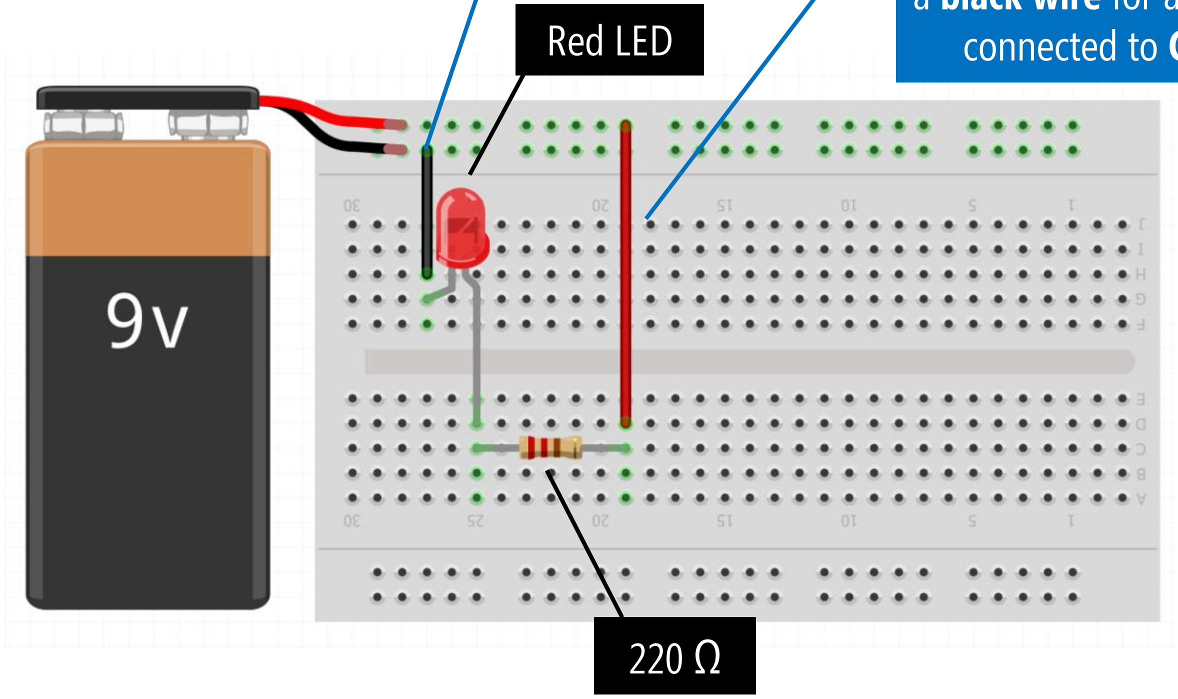
Let's make this on a breadboard!



EXERCISE: ONE POTENTIAL ANSWER

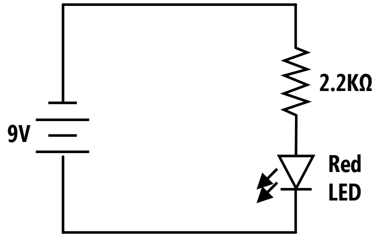
Let's make this on a breadboard!



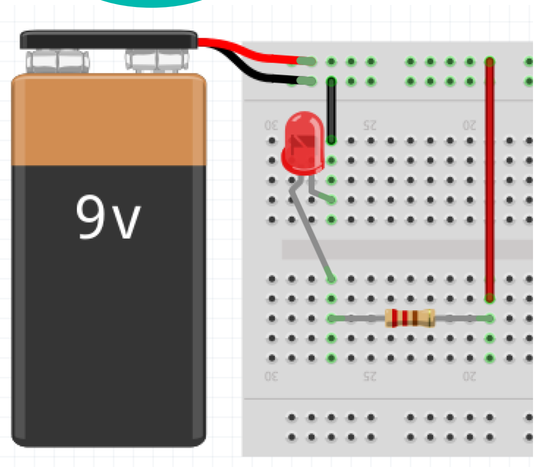


Breadboarding Tip: Carefully use wire color to indicate function. I like to use a **red wire** for any wire connected to Vs and a **black wire** for any wire connected to **GND**

EXERCISE: CORRECT OR INCORRECT?



Correct or Incorrect?



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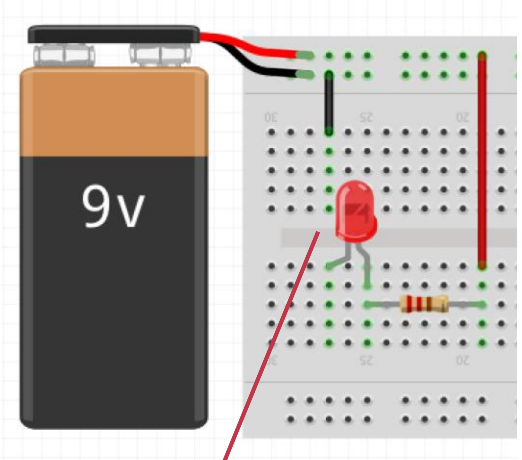

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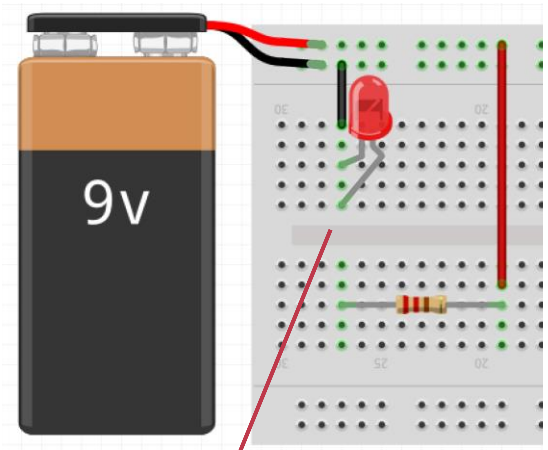

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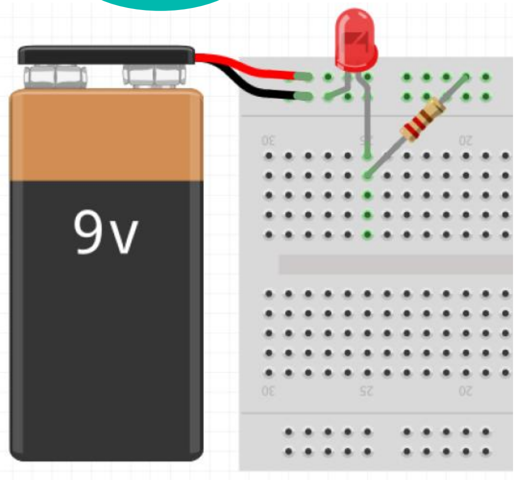
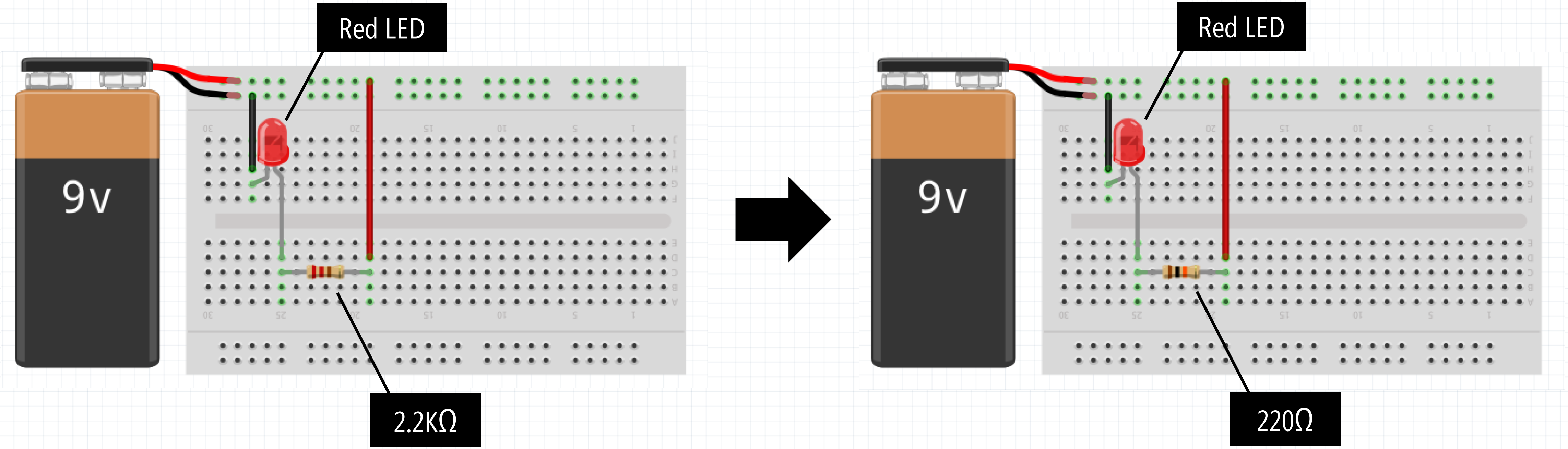


Recall that these **columns are not connected** across this split/gulf. So, the LED is not actually connected to the black wire (GND).

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 2.2K OHM RESISTOR WITH A 220 RESISTOR

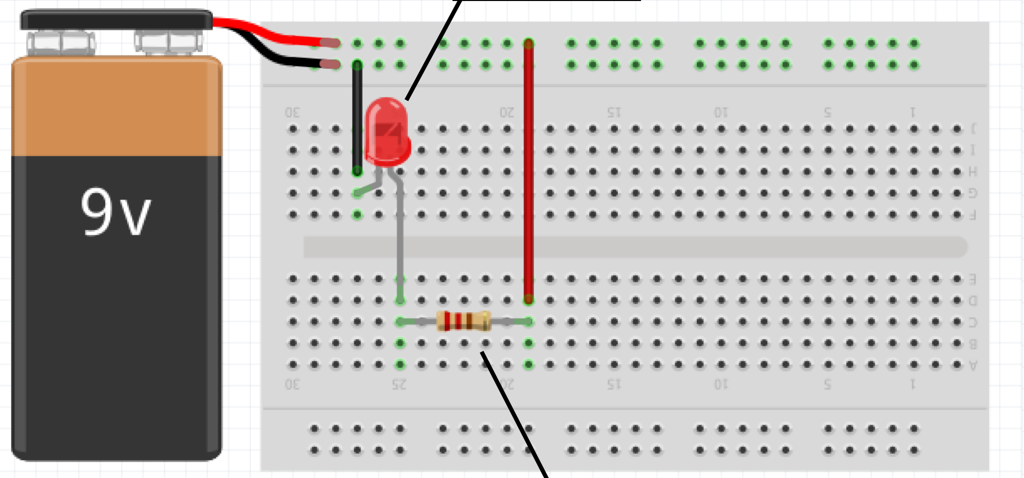


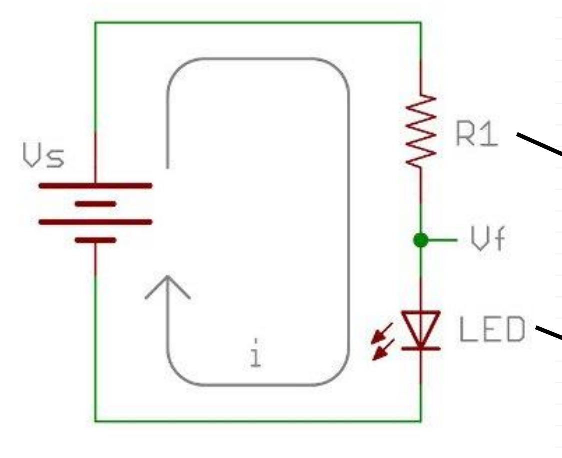
What happens to the LED? Does it get brighter or dimmer? Why?

EASY WAY TO TEST IF AN LED STILL WORKS

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

HOW TO SELECT AN APPROPRIATE CURRENT LIMITING RESISTOR





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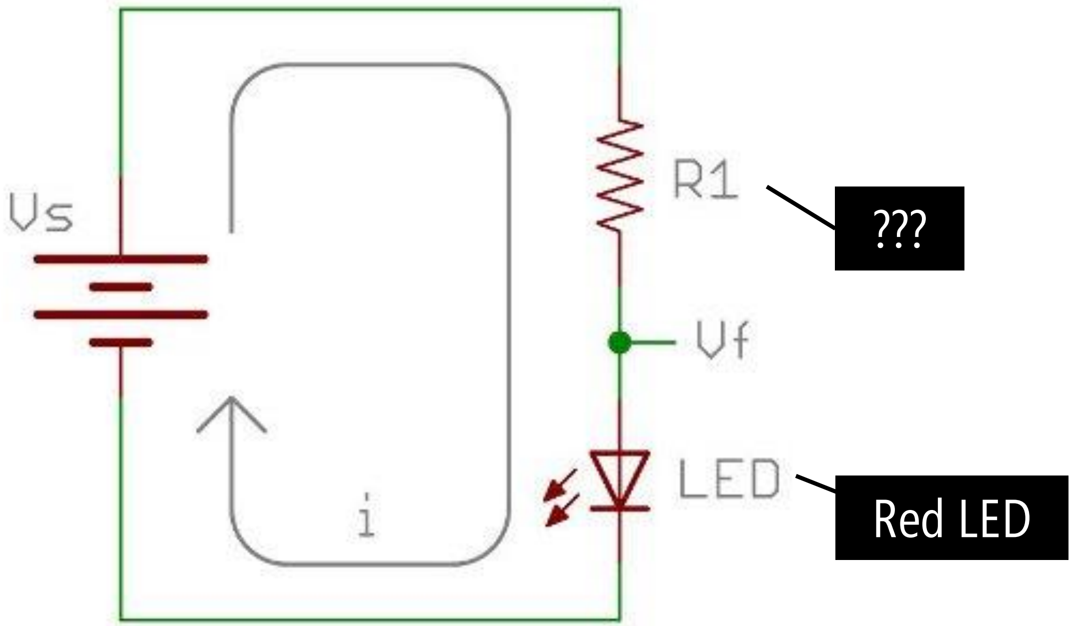

We need to know three things:

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

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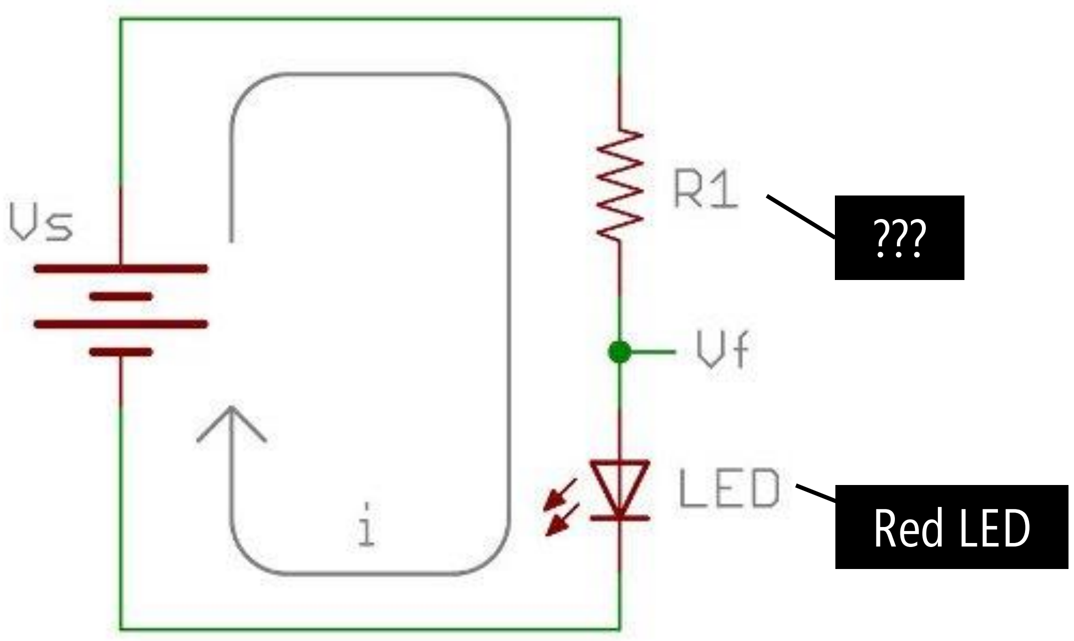

With these three values, use this equation derived from Ohm's Law to find the value of the resistor:

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

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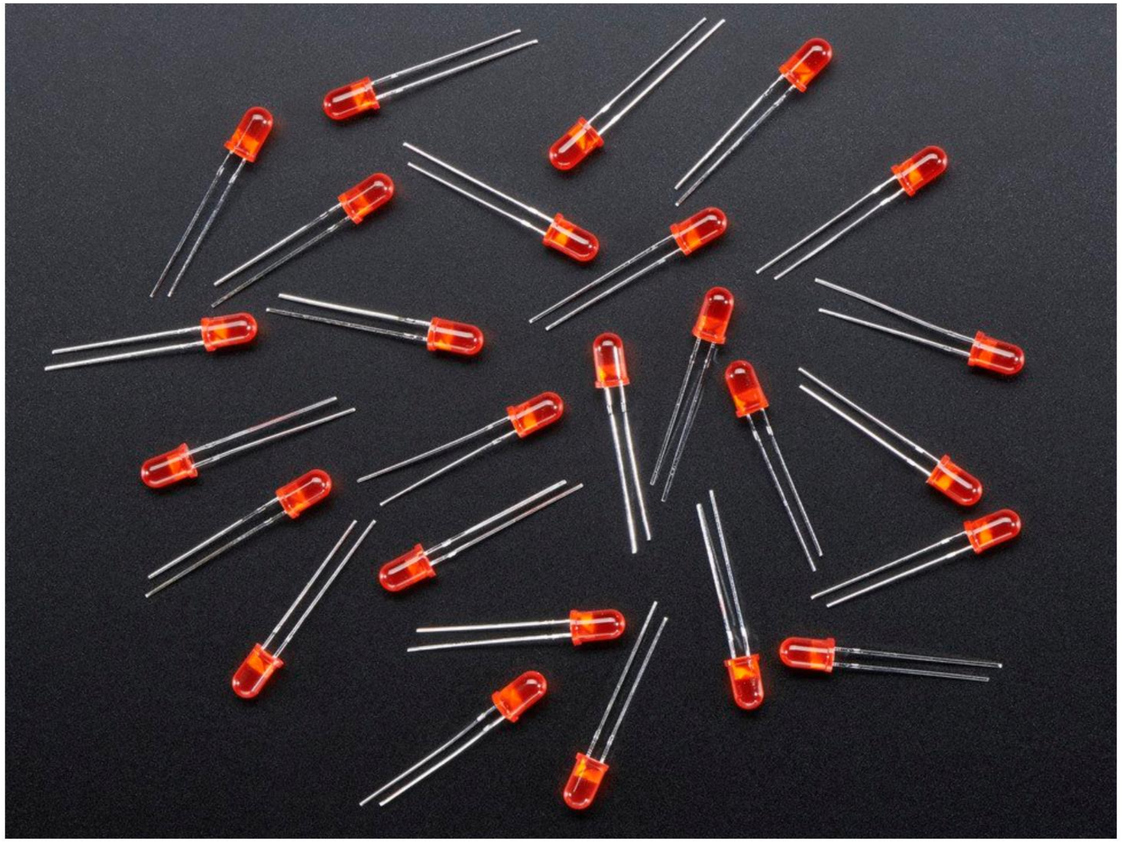
FINDING THE DATASHEET



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

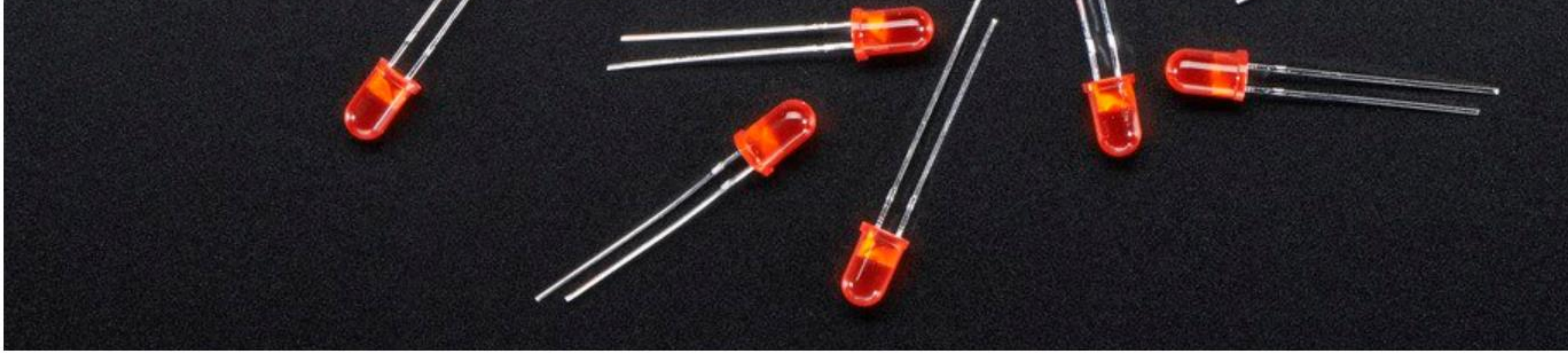
DESCRIPTION
TECHNICAL DETAILS
LEARN

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.



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Kingbright

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

Part Number: WP7113SRD/D   Super Bright Red

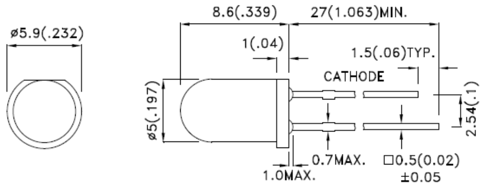
Features

- 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
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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

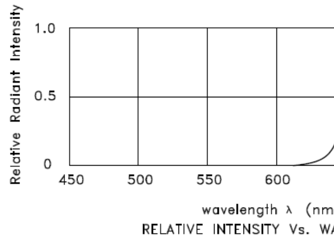
Notes:
1.Wavelength: +/-1nm.
2. Forward Voltage: +/-0.1V.

Absolute Maximum Ratings at TA=25°C

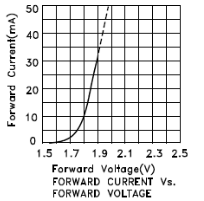
Parameter	Super Bright Red	Units
Power dissipation	75	mW
DC Forward Current	30	mA
Peak Forward Current [1]	155	mA
Reverse Voltage	5	V
Operating/Storage Temperature	-40°C To +85°C	
Lead Solder Temperature [2]	260°C For 3 Seconds	
Lead Solder Temperature [3]	260°C For 5 Seconds	

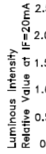
Notes:
1. 1/10 Duty Cycle, 0.1ms Pulse Width.
2. 2mm below package base.
3. 5mm below package base.

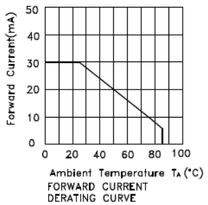
Kingbright

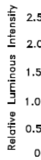


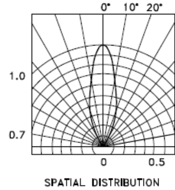
Super Bright Red   WP7113SRD/D











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 (V$_R$=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
λ_{peak}	Peak Wavelength	Super Bright Red	660		nm	I_F=20mA
λ_D [1]	Dominant Wavelength	Super Bright Red	640		nm	I_F=20mA
$\Delta\lambda_{1/2}$	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

Electrical / Optical Characteristics at TA=25°C

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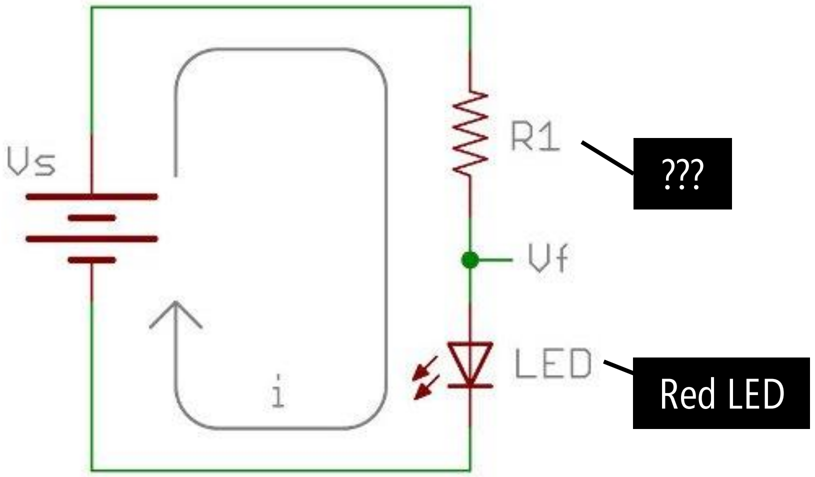
Notes:
1. 1/10 Duty Cycle, 0.1ms Pulse Width.
2. 2mm below package base.
3. 5mm below package base.



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

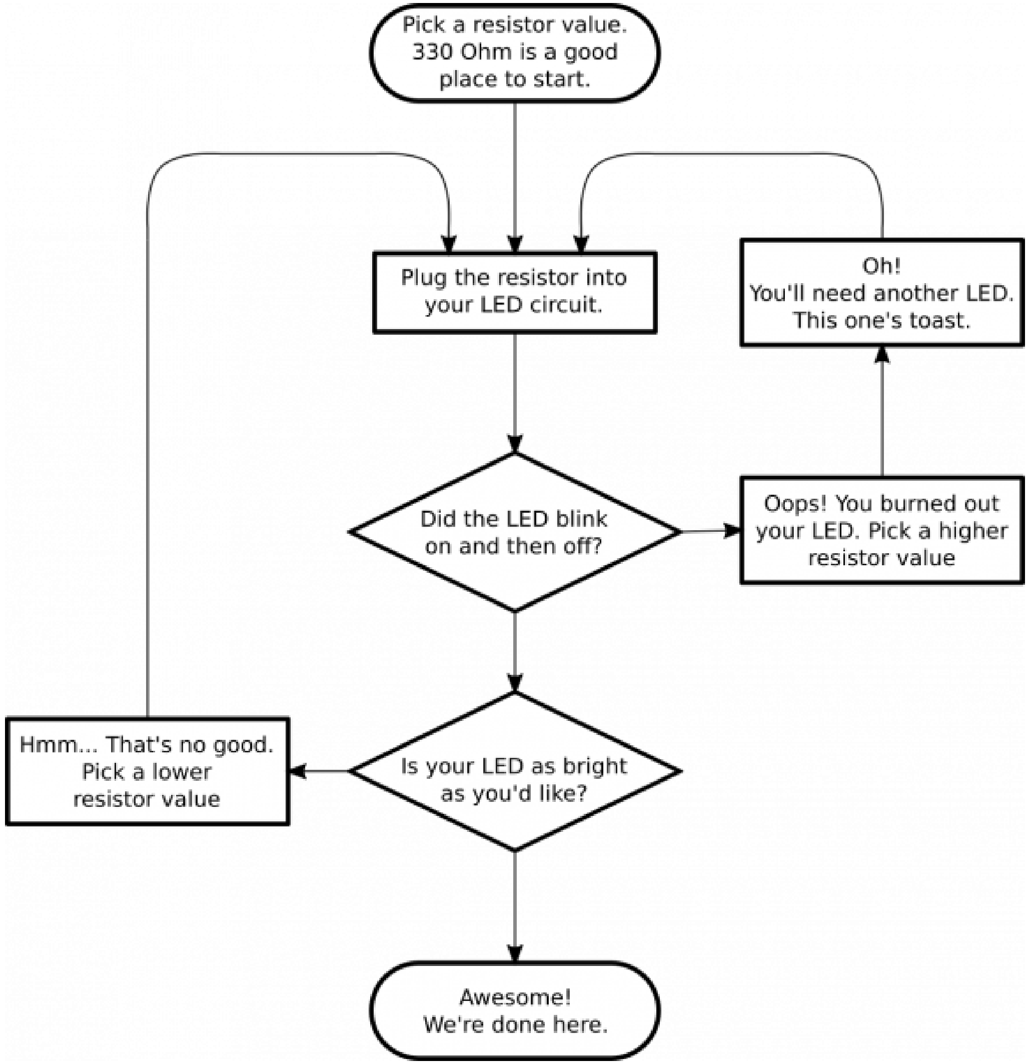
If you exceed the **Peak Forward Current**, your LED will **burnout**!

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 with a **5V supply**, **starting with a ~200-400Ω 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

REVIEW: TODAY WE WENT OVER…

What is a **circuit, voltage, current, and resistance**

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

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

What is **Ohm's Law** and why is it useful?

Series vs. **parallel** resistive circuit configurations

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

How to **read a datasheet**

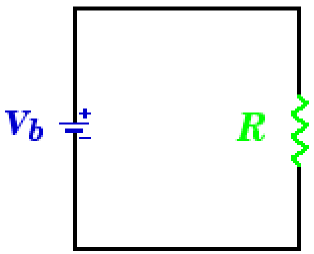
PHYSICAL COMPUTING 1: CIRCUITS

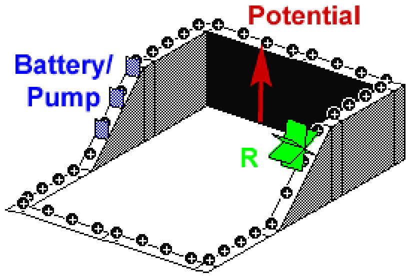
CSE 599 Prototyping Interactive Systems | Lecture 2 | April 4

Jon Froehlich • Jasper O'Leary (TA)

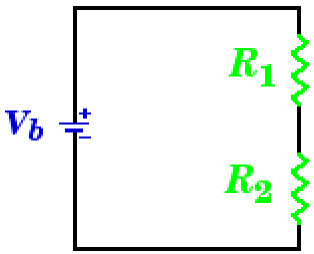
DESIGN USE BUILD
MAKEABILITY LAB
PAUL G. ALLEN SCHOOL OF COMPUTER SCIENCE & ENGINEERING
UNIVERSITY of WASHINGTON

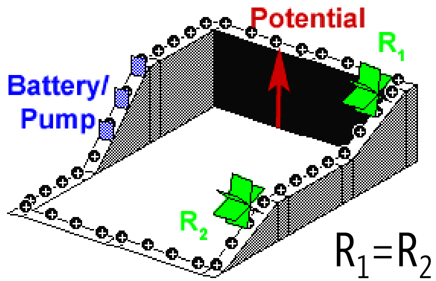
Build Intuition: Returning to our Water Analogy





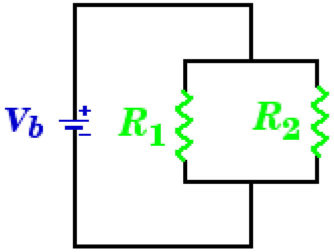
The vertical axis represents potential energy. The battery "pumps" the charges up to a higher potential. As the current turns the paddle, it does work and thus loses some energy similar to electrical current flowing through a resistor. Note: in this analogy, the slope is not significant.

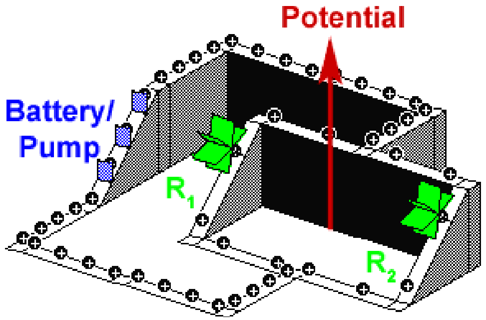




R_1=R_2

Here, the current passes through two resistors, losing some energy each time.



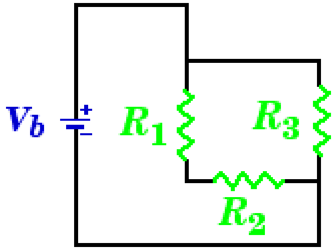


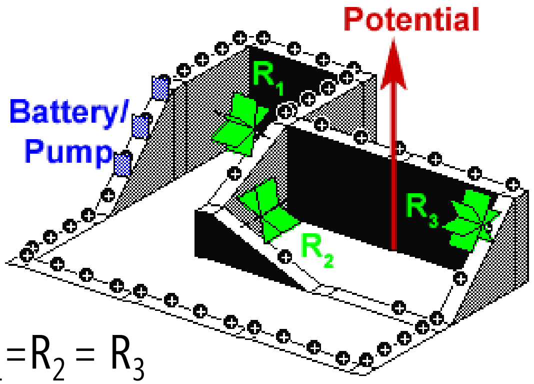
R_1=1.2 * R_2

Two resistors in parallel have the same voltage potential drop. The amount of charge flowing through the two branches is not the same in this case because R_1 is > than R_2, so more charge would flow through the smaller resistor (R_2) as current (just like water) takes the path of least resistance.

[source: http://faculty.wwu.edu/vawter/PhysicsNet/Topics/DC-Current/WaterFlowAnalog.html]

Build Intuition: Returning to our Water Analogy



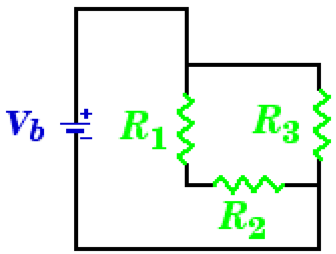


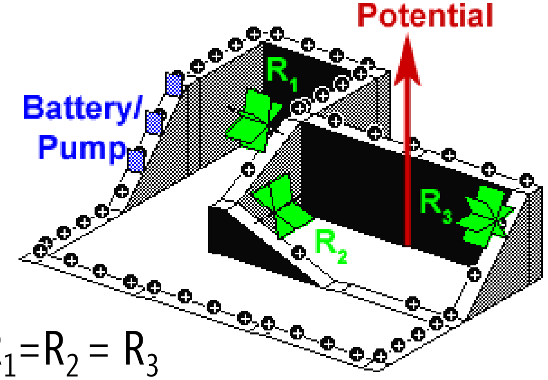
$R_1 = R_2 = R_3$

What happens in this circuit?
R_1 and R_2 are in series while their combination (called R_{12}) is in parallel with R_3?

[source: http://faculty.wwu.edu/vawter/PhysicsNet/Topics/DC-Current/WaterFlowAnalog.html]

Build Intuition: Returning to our Water Analogy





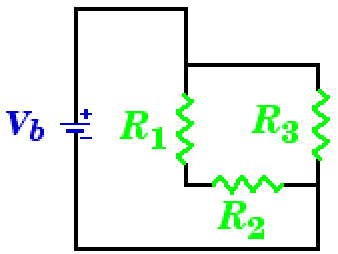
$R_1 = R_2 = R_3$

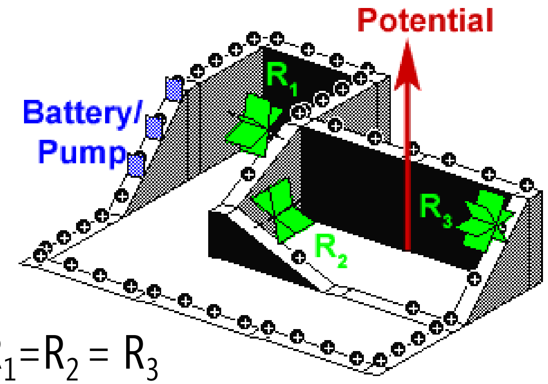
What happens in this circuit?
R_1 and R_2 are in series while their combination (called R_{12}) is in parallel with R_3?

Answer:
The voltage drop across R_{12} is the same as R_3 since they are in parallel. Half the current, however, flows through the R_{12} branch since this branch has twice the resistance as the R_3 branch.

[source: http://faculty.wwu.edu/vawter/PhysicsNet/Topics/DC-Current/WaterFlowAnalog.html]

EXAMPLE: SOLVING FOR R_{TOT} WITH SERIES AND PARALLEL RESISTORS





$R_1 = R_2 = R_3$

Calculate the equivalent resistance (R_{tot}) for this circuit.

[source: http://faculty.wwu.edu/vawter/PhysicsNet/Topics/DC-Current/WaterFlowAnalog.html]

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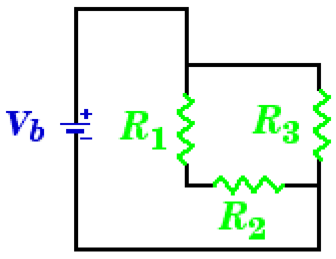

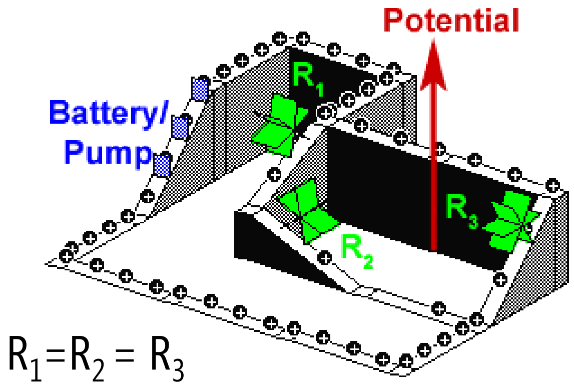

Calculate the equivalent resistance (R_{tot}) for this circuit.

Answer:

Given R_1 and R_2 are in series, then $R_1 + R_2 = R_{12}$

R_{12} is in parallel with R_3, so we can use the shortcut parallel resistance equation:

$$R_{12} * R_3 / (R_{12} + R_3)$$

Thus, R_{tot} equals:

$$R_{12} * R_3 / (R_{12} + R_3)$$

[source: http://faculty.wwu.edu/vawter/PhysicsNet/Topics/DC-Current/WaterFlowAnalog.html]