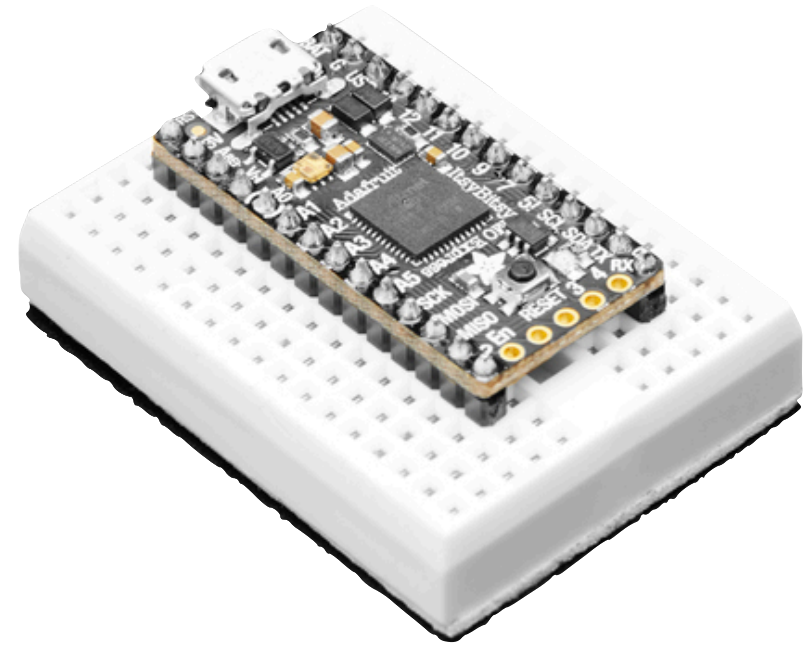
Technical topic

Microcontrollers & electricity

Landing people on the moon

What 55 years of progress gets you

Apollo guidance computer
~85 KHz (0.085Mhz)
~4K RAM
~72K ROM
size of a spaceship



Itsy Bitsy M0

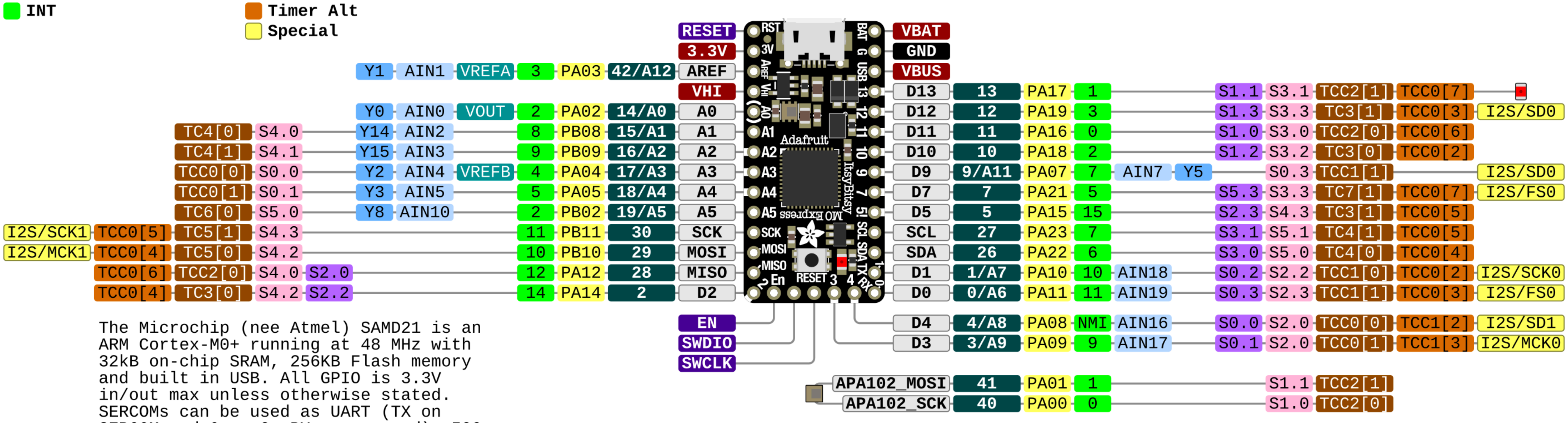
48 MHz	~570x faster
32K RAM	8x as much
256KB flash	4x as much
size of a quarter	

→ Apples and oranges,
but in the same ballpark (for €4–€5)

Itsy Bitsy M0 Express

https://www.adafruit.com/product/3727

- Power
- GND
- Control
- CircuitPython Name
- Arduino Name
- GPIO
- INT
- DAC/AREF
- ADC
- Touch
- SERCOM
- SERCOM Alt
- Timer
- Timer Alt
- Special



The Microchip (nee Atmel) SAMD21 is an ARM Cortex-M0+ running at 48 MHz with 32kB on-chip SRAM, 256KB Flash memory and built in USB. All GPIO is 3.3V in/out max unless otherwise stated. SERCOMs can be used as UART (TX on SERCOM pad 0 or 2, RX on any pad), I2C (SDA on pad 0, SCL on pad 1), or SPI (SCK on pad 1 or 3, MOSI on pad 0 or 3 (SCK on pad 1) or pad 0 or 2 (SCK on pad 3), MISO on any pad remaining)

Demo time

Electricity! ⚡

These slides adapted from Scott Hudson, CMU

What is electricity?

It is not something that we can touch, see, smell, or hear so there is a little bit of abstraction.

It is a broad term that refers to a set of phenomena caused by electric fields, and the presence or movement of electric charges.

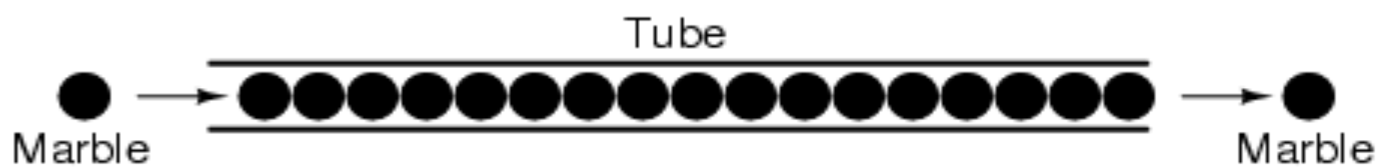
- Electrons are the charged parts of atoms that can typically move around

It is tightly coupled with magnetism: *Where ever you have a moving electric field, you have a magnetic field and vice versa.*

The details are modeled by some relatively complicated math

Electron Flow

Pushing electrons through a wire is similar to pushing marbles through a straw.



When an additional electron is added to one end of the wire, a force is propagated through the wire (at typical speeds of 66% to 97% of the speed of light, depending on the wire). This force is the electrical signal that is used to do work and for communication.

However, the physical movement of individual electrons is extremely slow – a few centimeters per hour.

Voltage and Current

In designing and analyzing electric circuits, there are two things we like to keep track of:

Voltage (symbol: *V* or *E,* units: *volts* [V])

The difference in electric potential between two points.

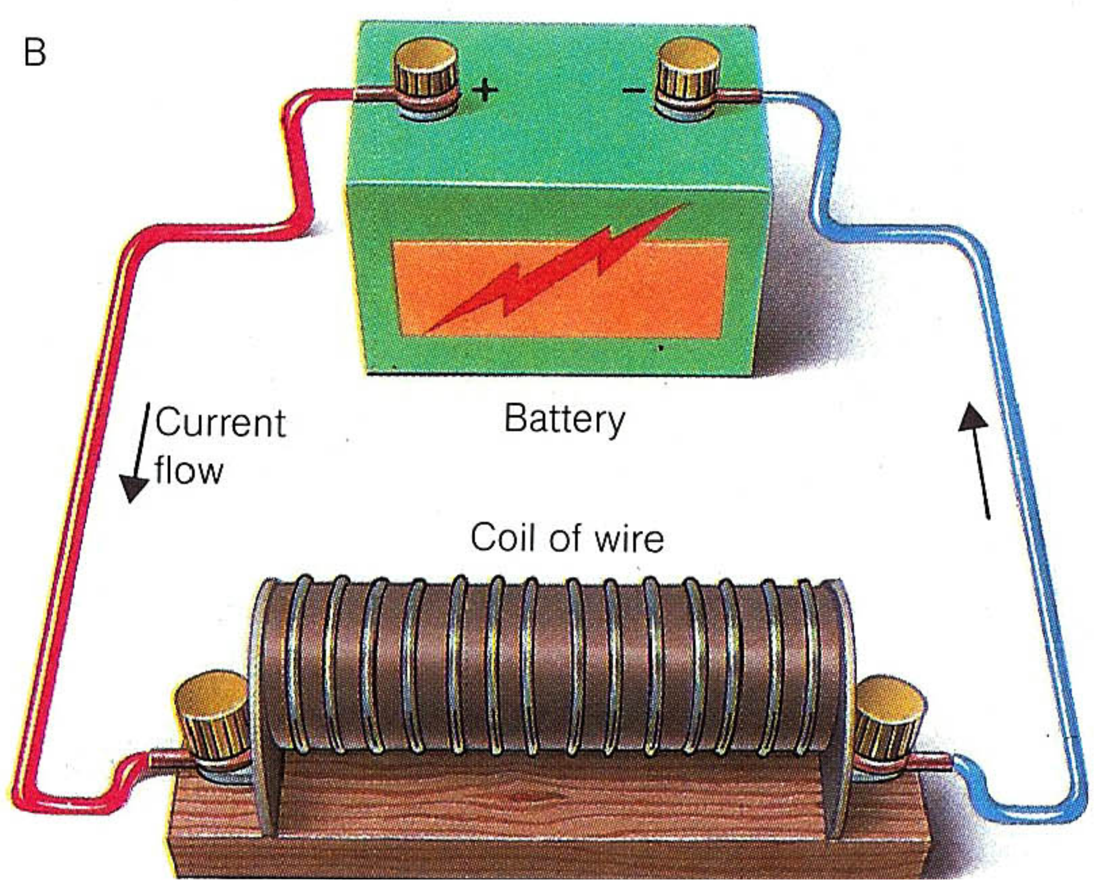
Current (symbol: *I,* units: *amps* [A])

The rate of flow of electric charge past a point.

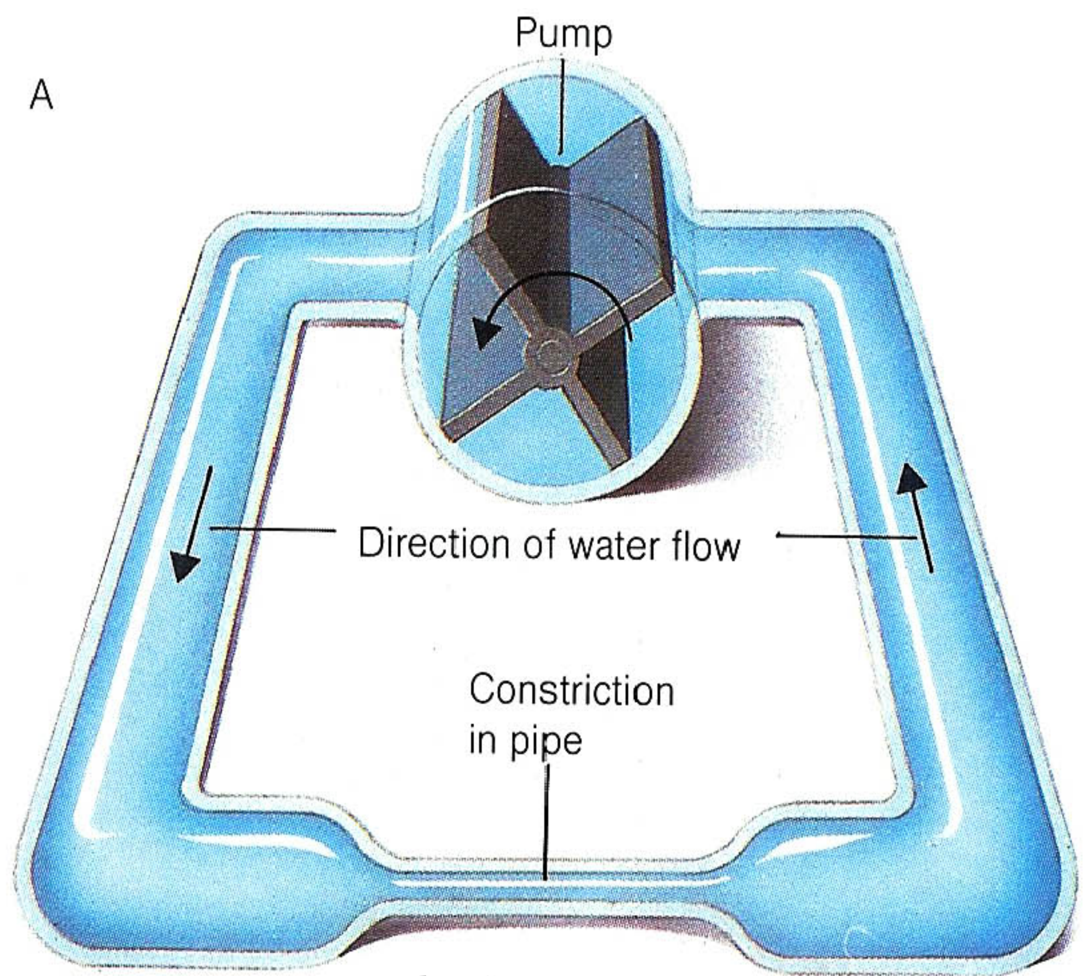
Water Analogy

Voltage ~= Pressure (PSI)
Current ~= Flow (GPM)

Voltage Source



Pressure Source



Resistance

Voltage

Voltage is a measure of **difference** in electric potential.

It is a relative measure, just like pressure (or distance).

Usually we talk about voltage ***across*** a component (one side vs. the other) or we talk about voltage relative to a common reference point.

For air pressure, the common reference is atmospheric pressure.

For voltage, the common reference point is called ***ground***.

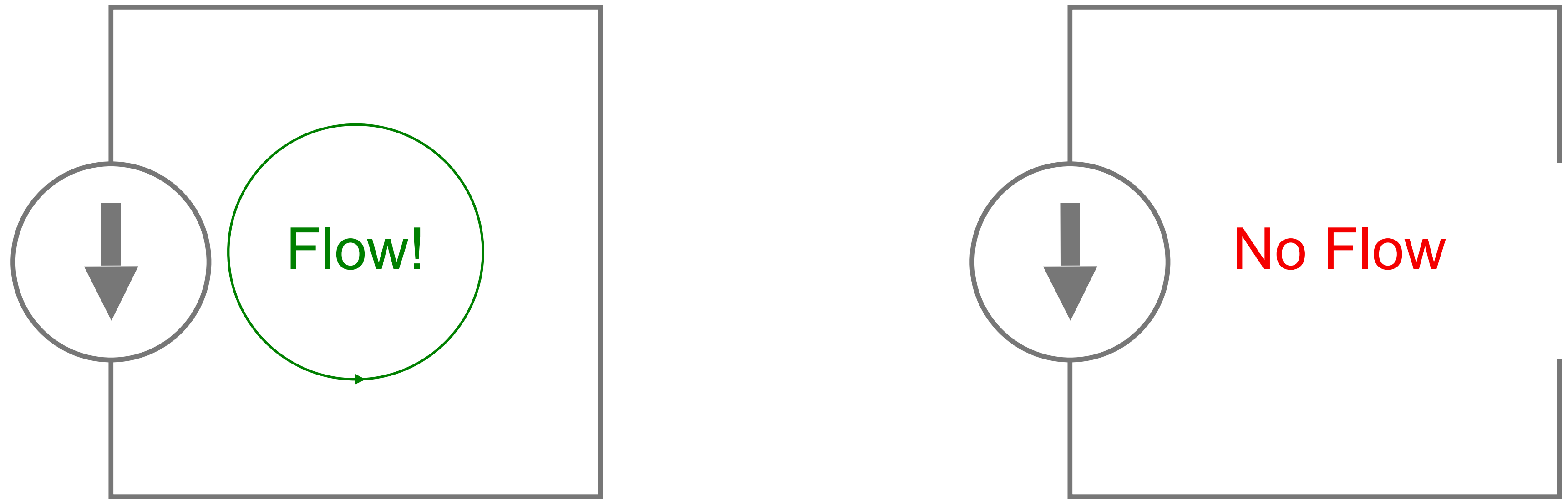
This can literally mean Earth ground, but usually means the negative terminal of the power supply.

Current

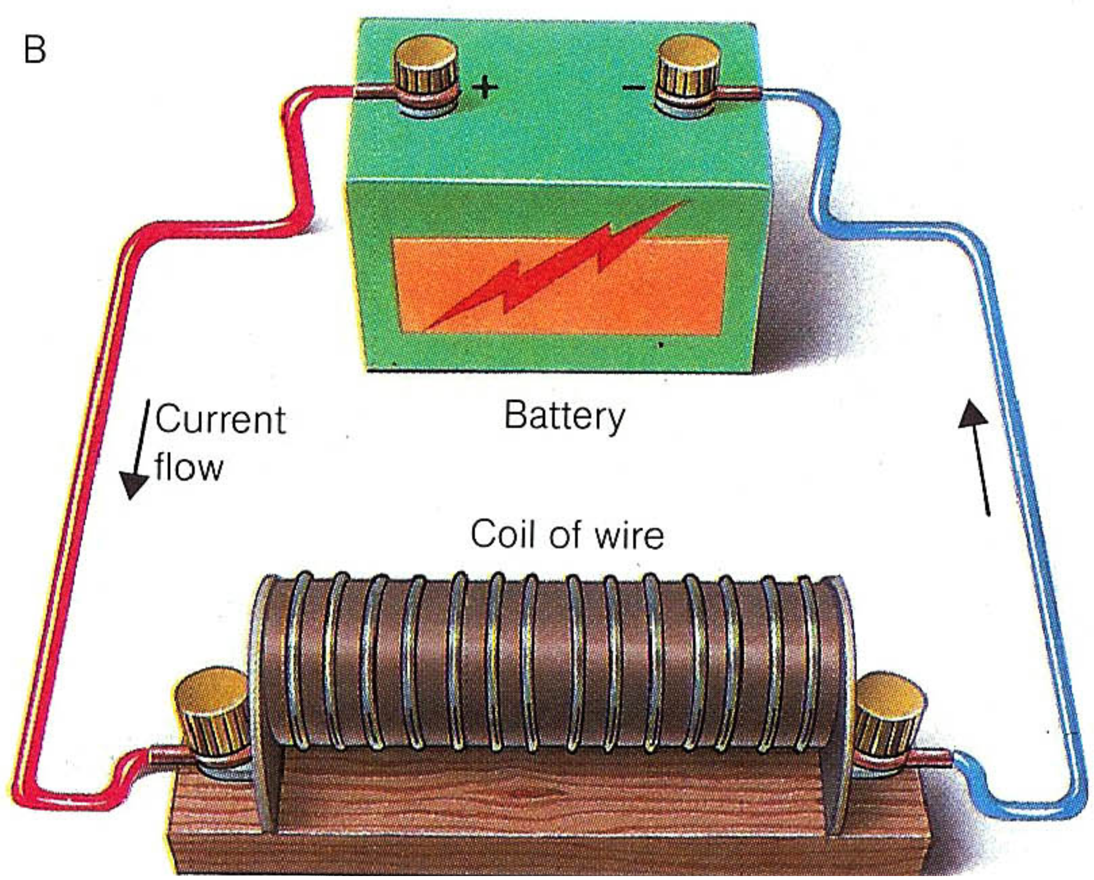
Current: the measure of the flow of electrons from one point to another ***through*** a given point or component.

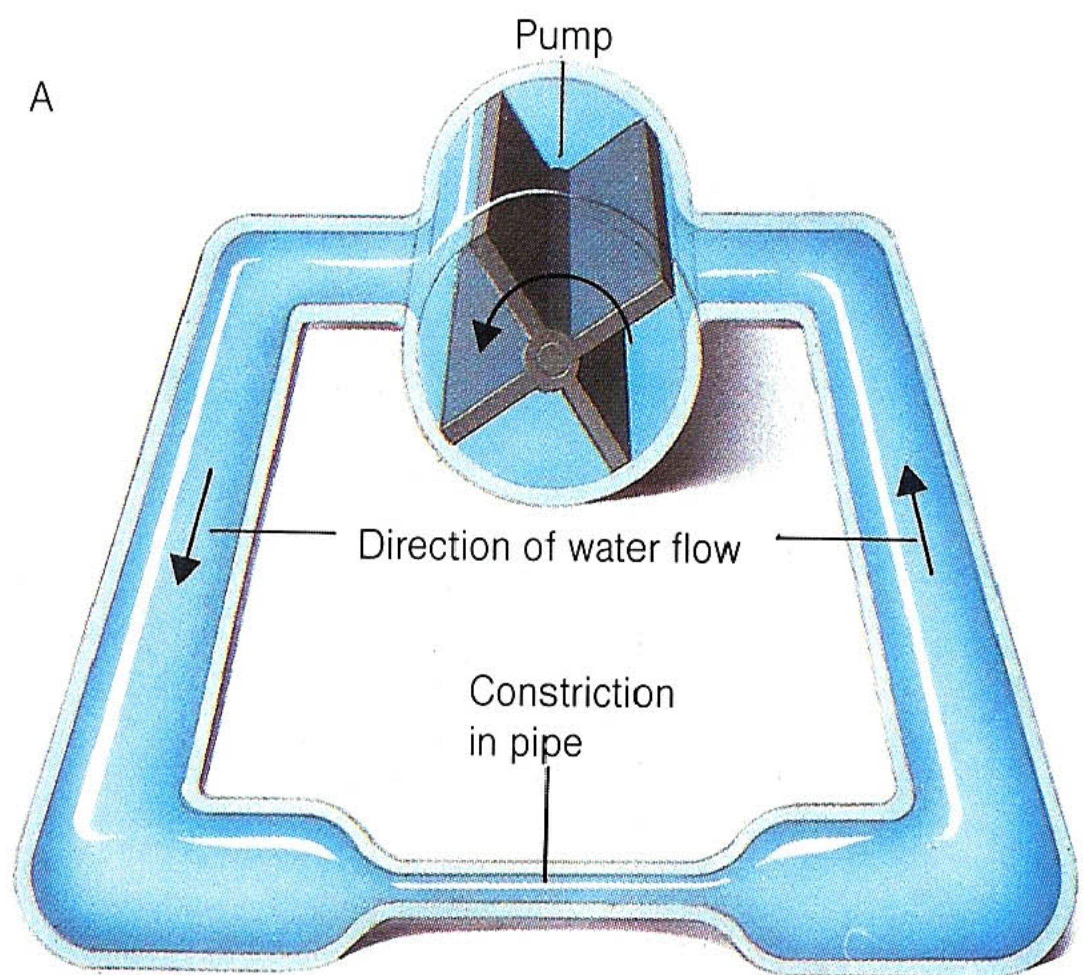
In order for current to flow, the electrons need a place to go – just like water, except electrons
can't just fall out onto the floor.

There needs to be a complete return path back to the power source (a ***circuit***)



Back to the water analogy





Resistance

Resistance

Resistance (symbol: *R,* units: *ohms* [Ω])

A measure of how difficult it is to push current through a circuit or component.

High resistances fight the flow of current. To maintain a given current flow, a higher voltage (pressure) is needed.

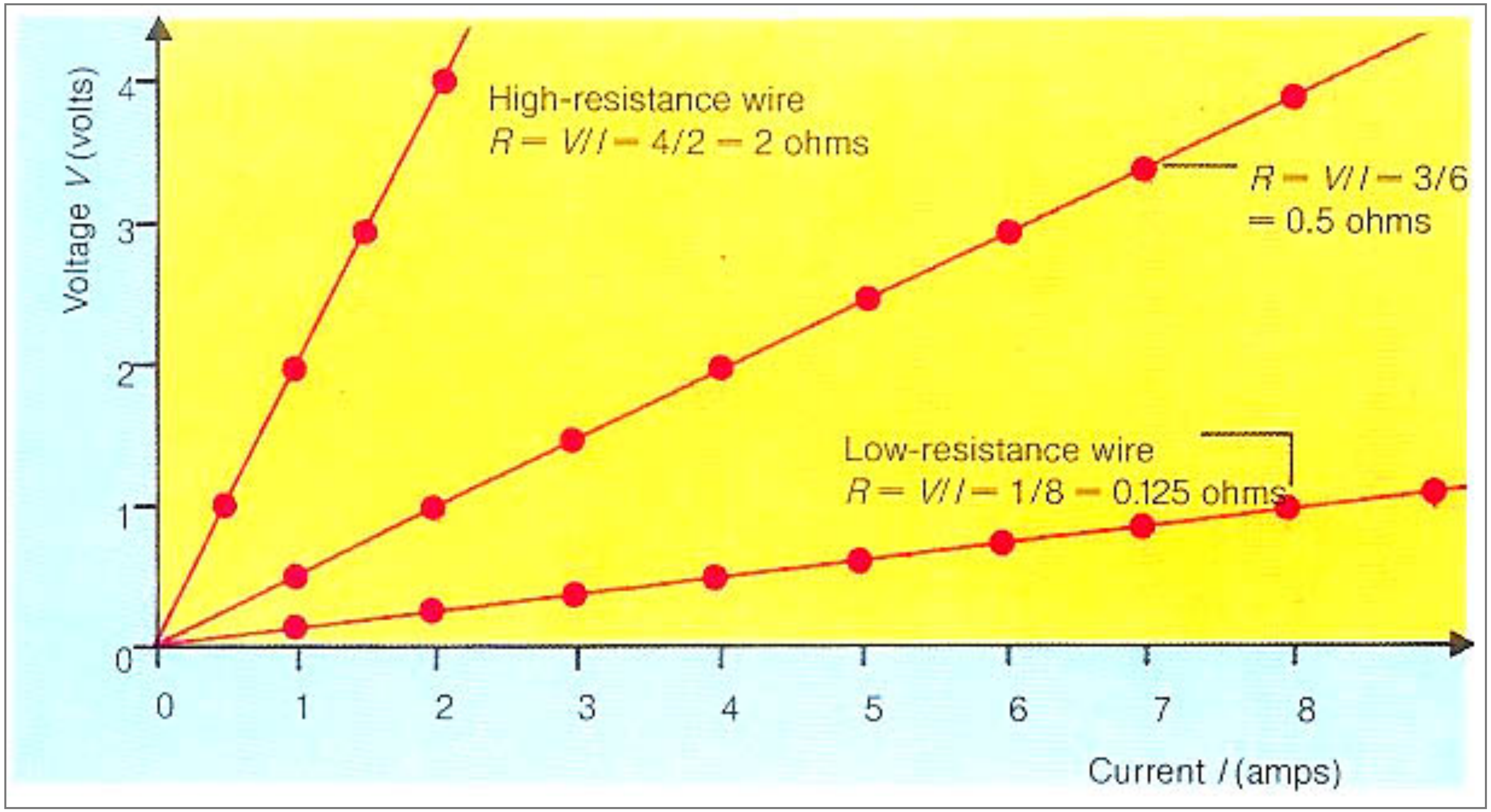
Low resistances easily allow current to pass through. Thus, lower voltage (pressure) is needed to maintain a given current flow.

Ohm’s Law

V= I*R

Voltage = Current * Resistance

Georg Ohm



Conductors vs. Insulators

Conductors typically have very low resistance

Copper has resistivity of 1.7×10^{-8} Ω per meter

Insulators typically have very high resistance

Glass has resistivity of 1×10^{12} Ω per meter

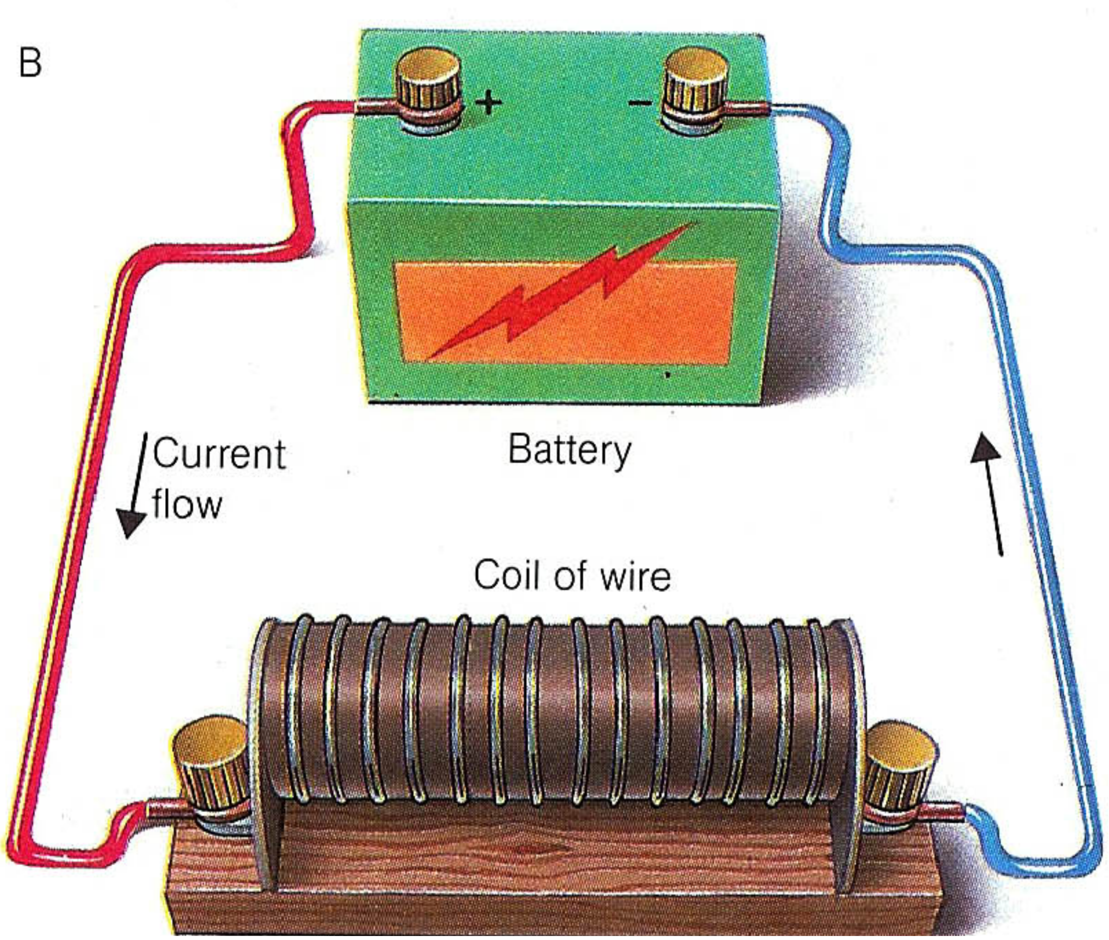
Not critical, but… *Resistivity* is a material property used for calculating resistance given the dimensions of the wire.

$$R = \frac{\rho l}{A} \qquad \text{Resistance} = \frac{\text{Resistivity * Length}}{\text{Cross-sectional Area}}$$

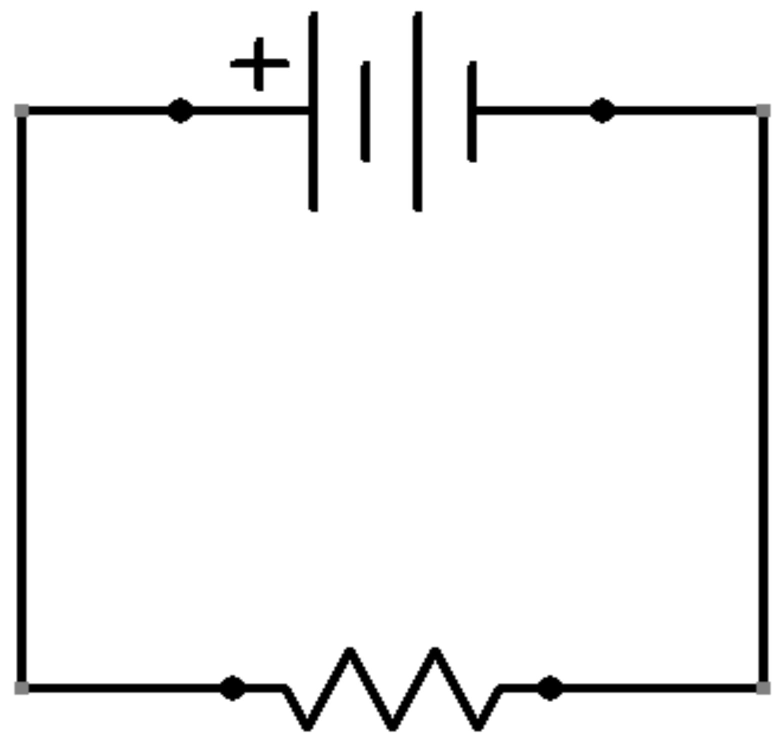
In simpler terms:

WireResistance(*thick*, *short*) < WireResistance(*thin*, *long*)

Simple Circuit Diagram



Pictorial diagram



Schematic diagram

Schematic Diagrams

Describes the functional components of a circuit

→ What the parts <u>do</u>

and how they are electrically connected

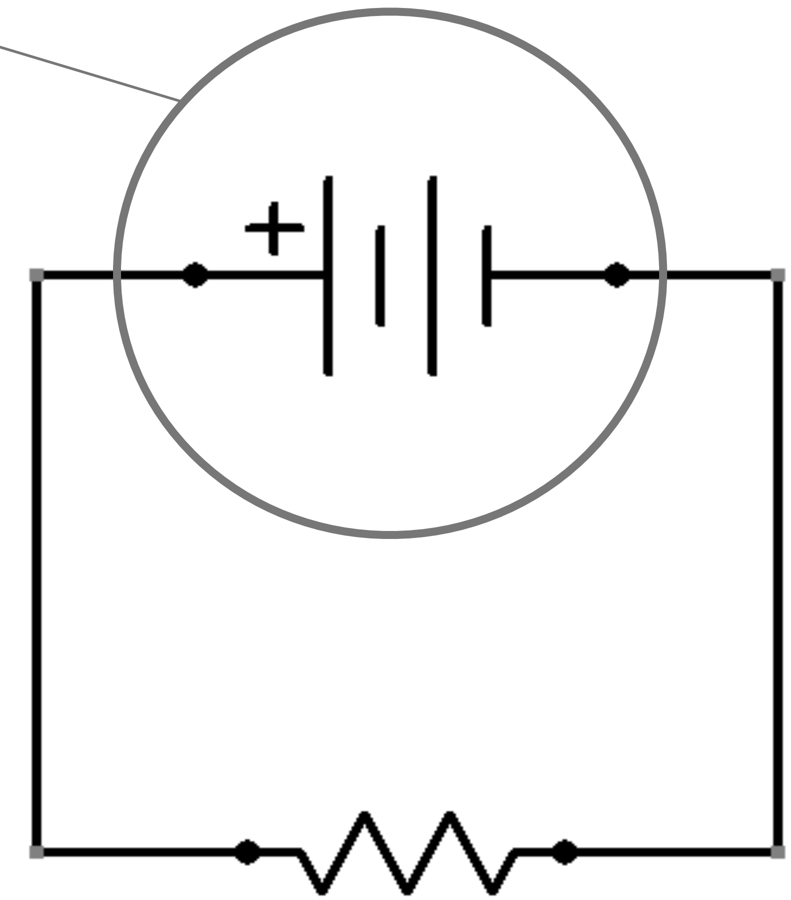
But abstract away details

Physical form of components

Location of components

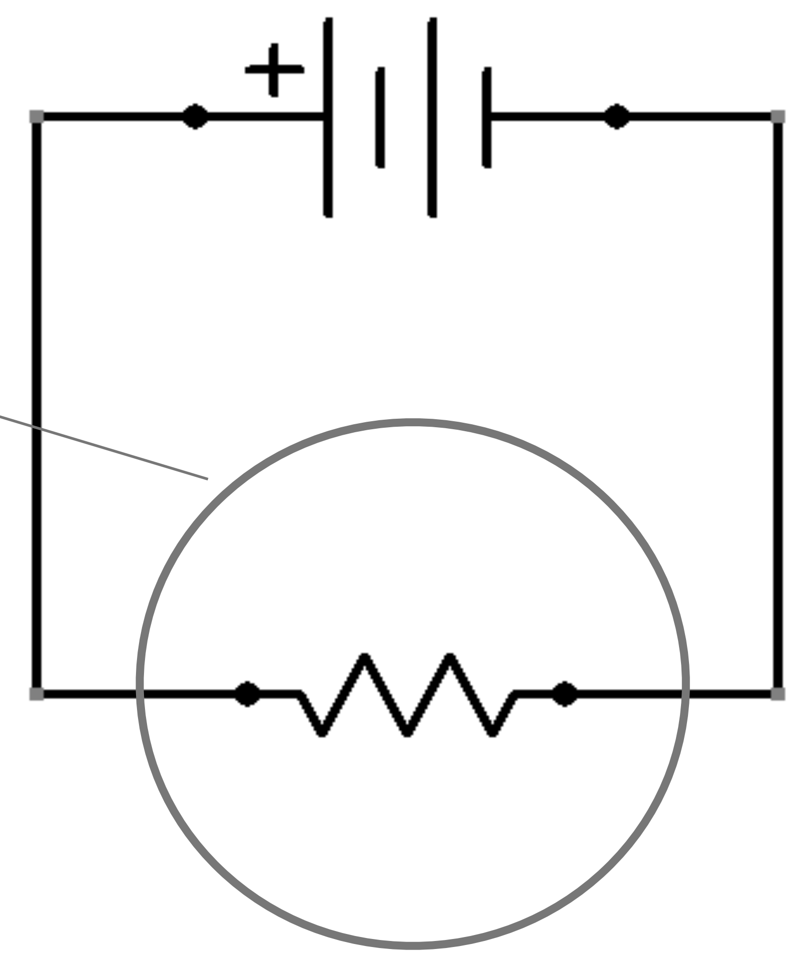
Schematic Diagrams

Battery
- source of power
- typically tries to provide a constant voltage



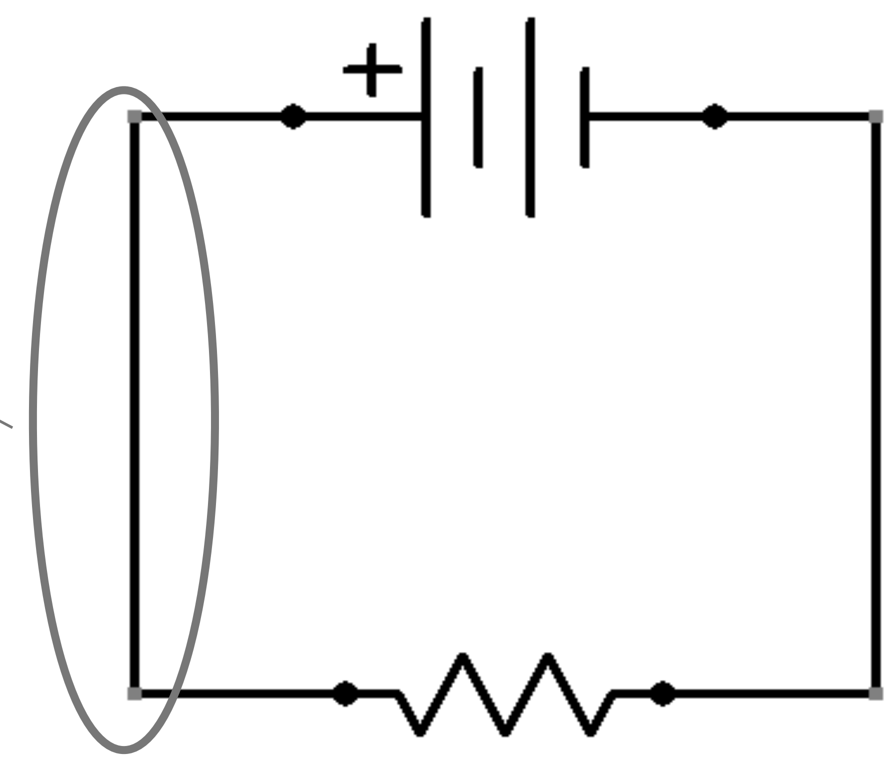
Schematic Diagrams

Resistor
- Something that provides resistance

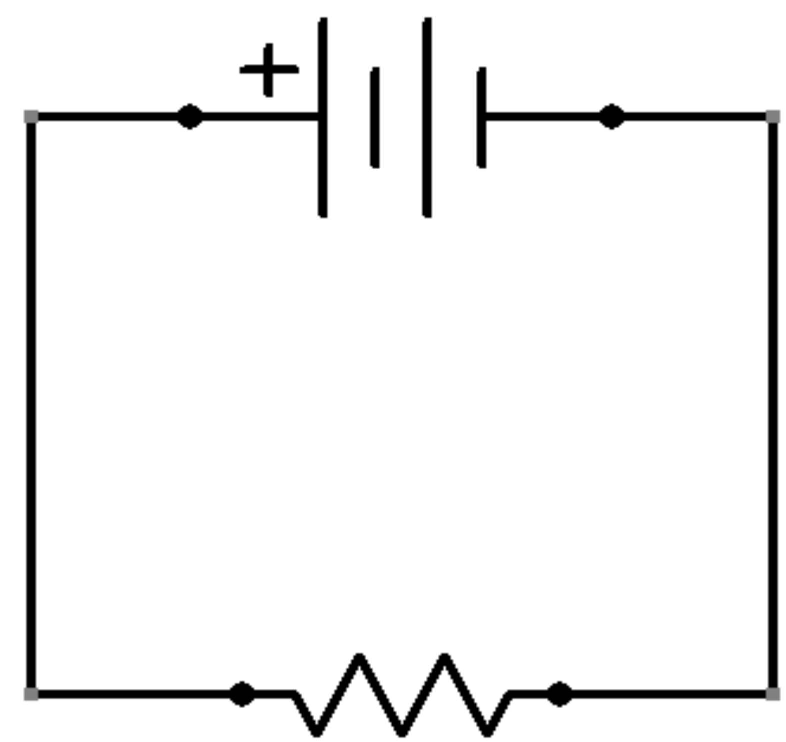


Schematic Diagrams

Conductive path
- Represents electrical connection
- Path that current can flow over
- Most typically a wire or PCB “trace”



Schematic Diagrams

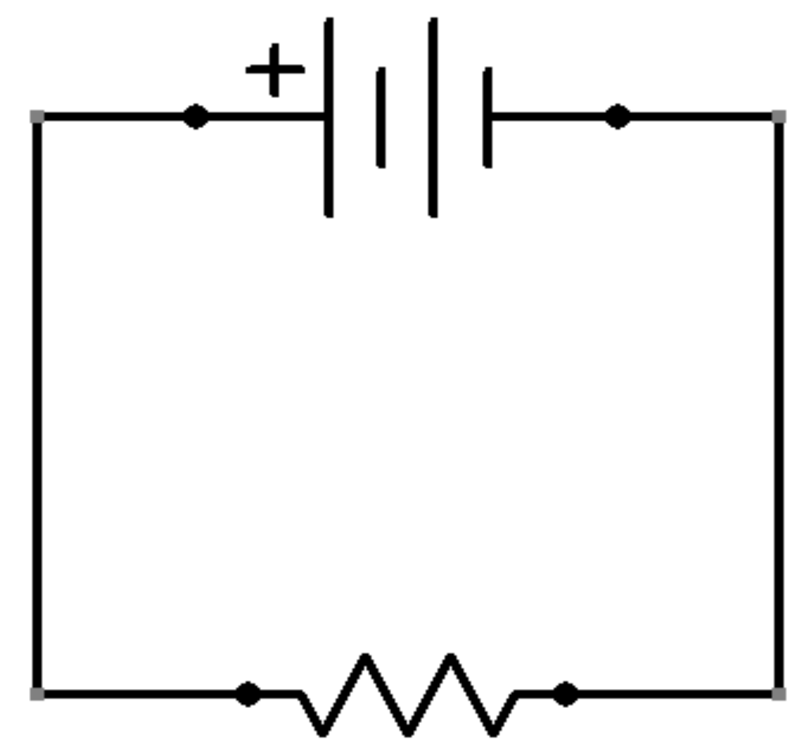


Will talk about conventions and symbols for other kinds of components later

Schematic Diagrams

Note that we pretty much <u>always</u> have closed loops (AKA "circuits") with a driving power source

- may be several/many such loops



So much so that we often use a shorthand notation so we don't need draw connections to the power source over and over again

Schematic Diagrams

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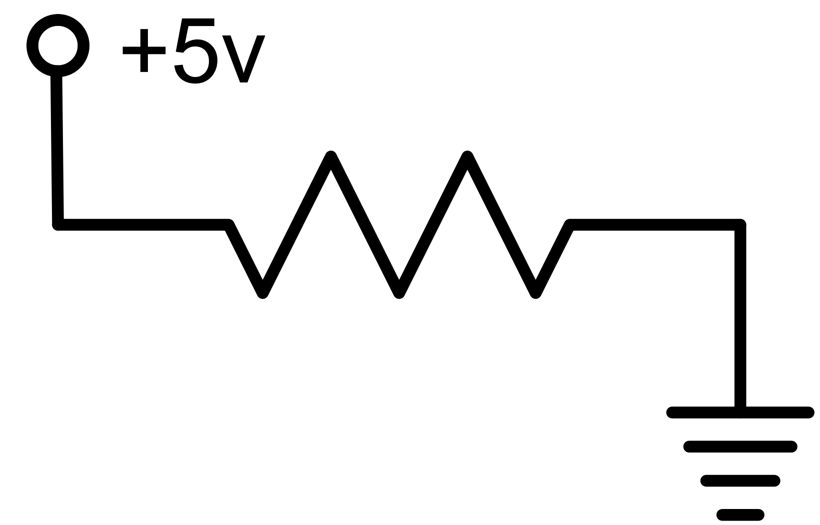
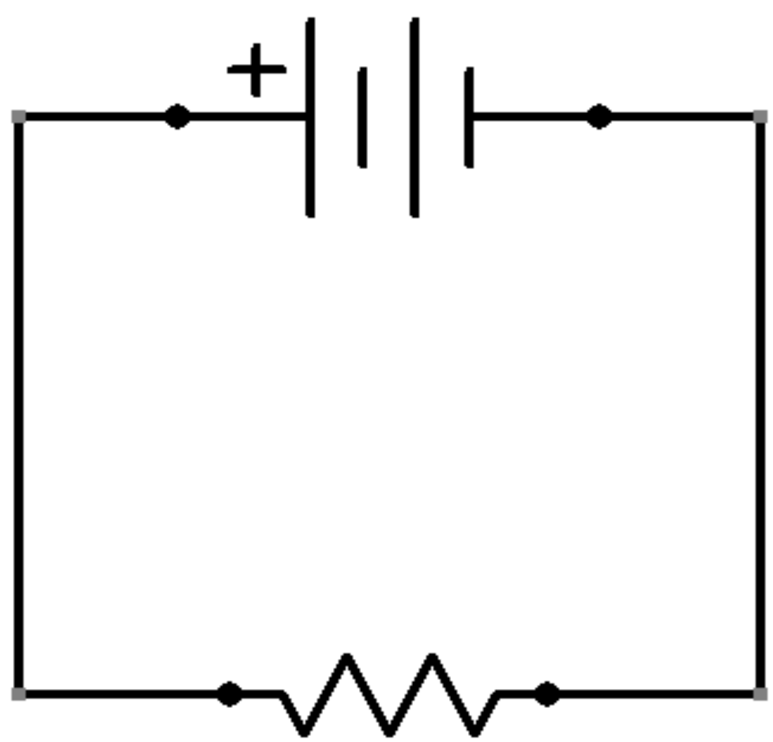


So much so that we often use a shorthand notation so we don't need draw connections to the power source over and over again

Even though we often don't show the power source,
It's always there and we always "loop through it"

Schematic Diagrams



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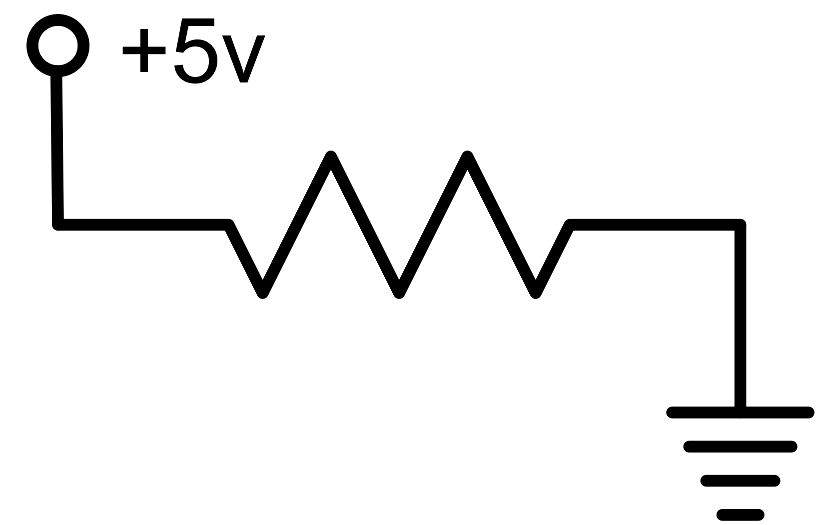
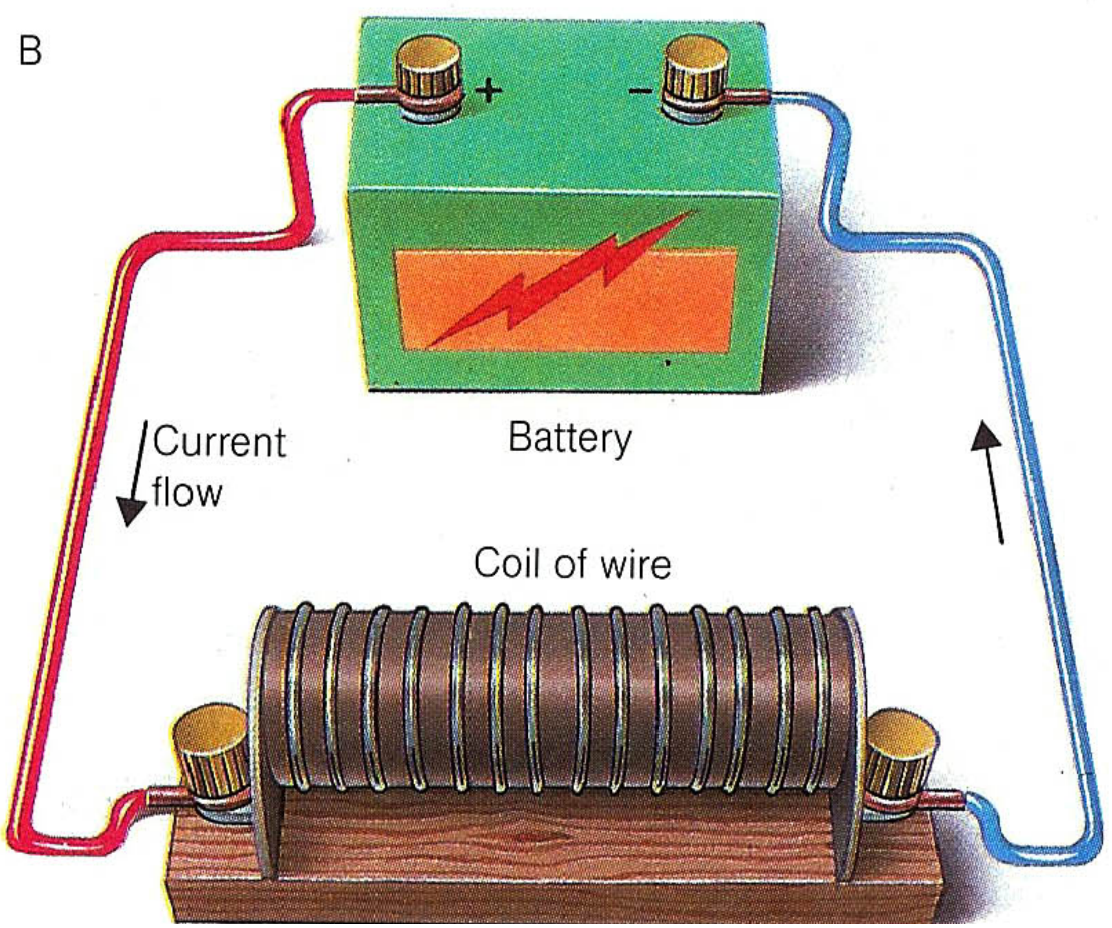
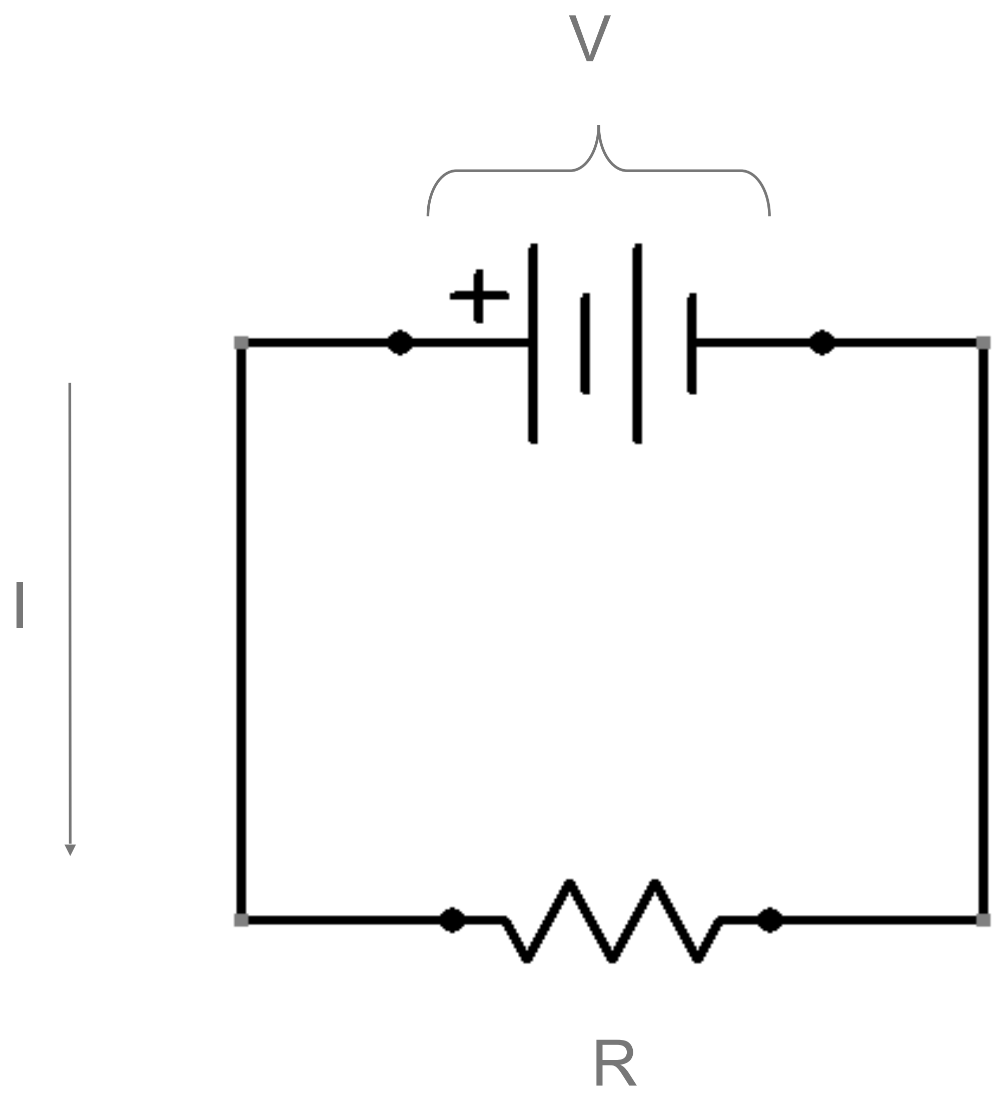


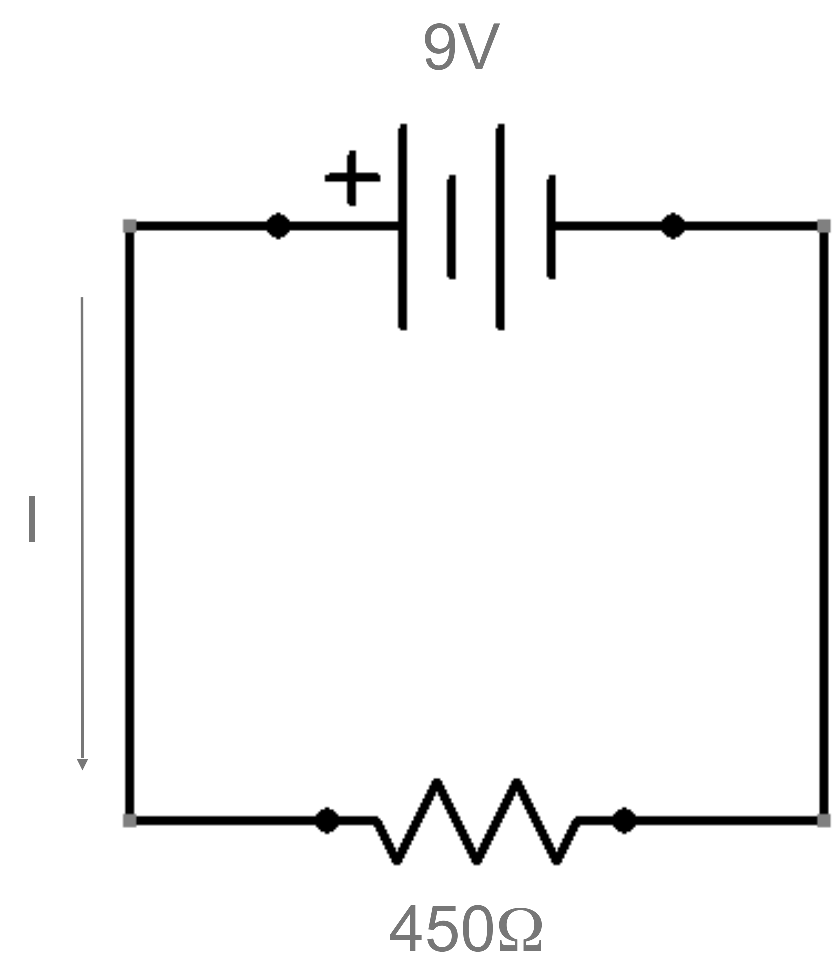
Simple Circuit Diagram





Applying Ohm’s Law

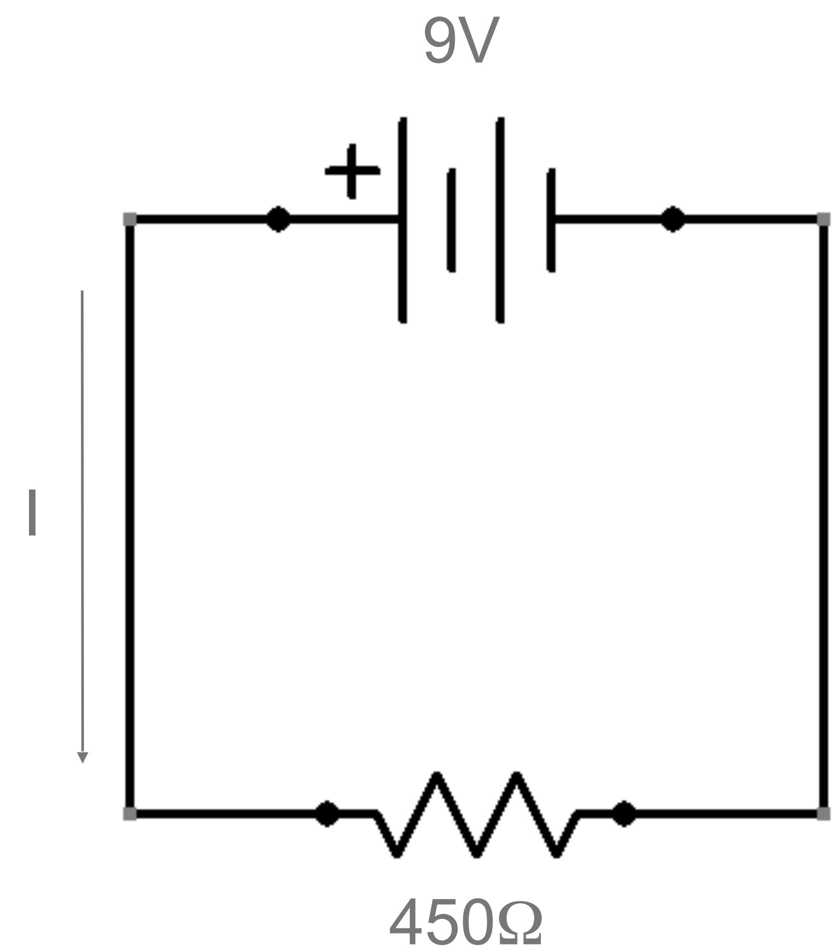
What is I (the current through this circuit)?



Applying Ohm's Law

What is I (the current through this circuit)?

$$V = IR$$

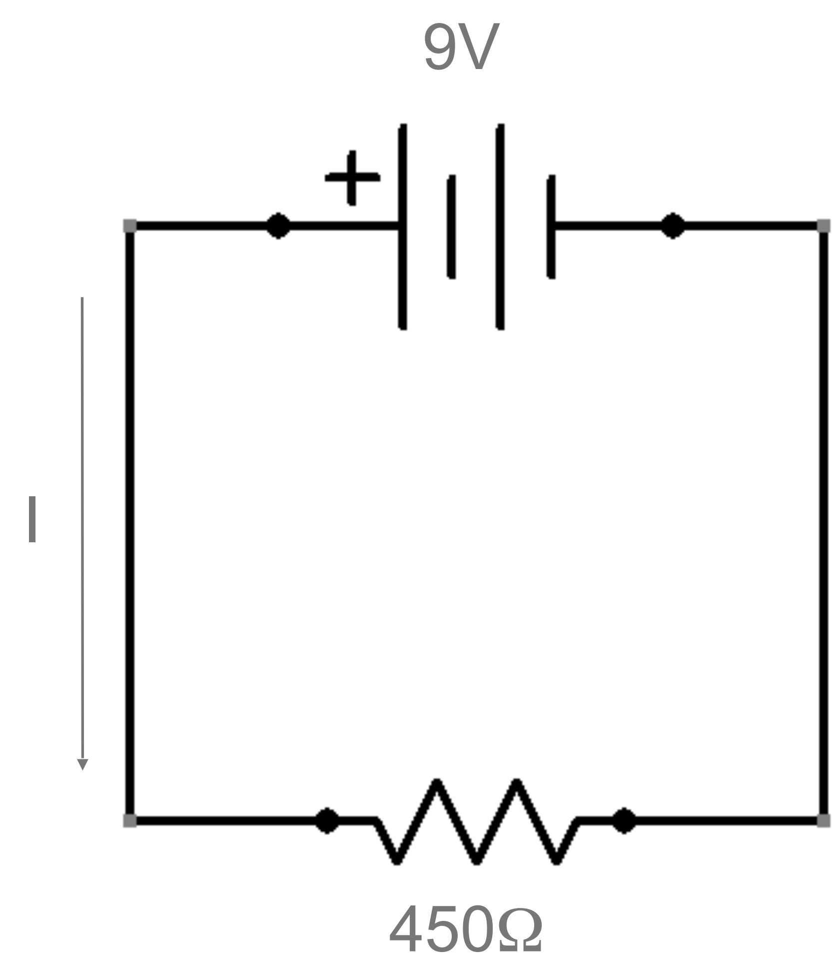


Applying Ohm's Law

What is I (the current through this circuit)?

$V = IR$

$I = V/R$

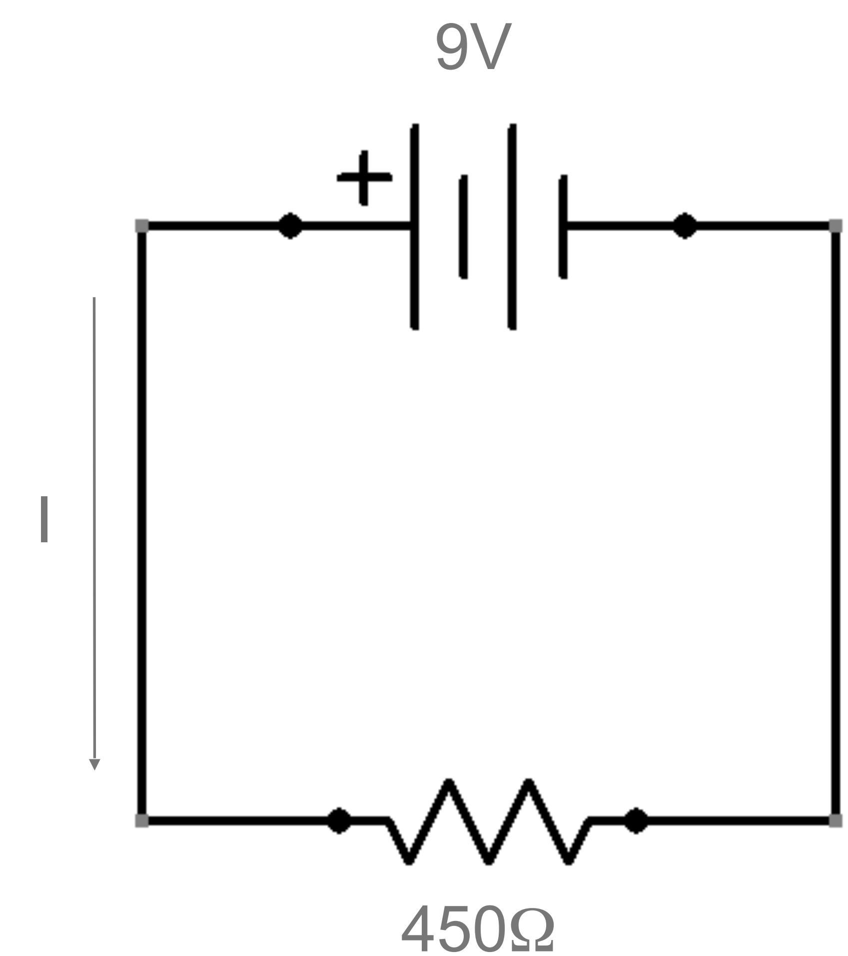


Applying Ohm's Law

What is I (the current through this circuit)?

$$V = IR$$

$$I = V/R$$
$$I = 9V/450\Omega$$
$$I = 0.02A$$



Applying Ohm's Law

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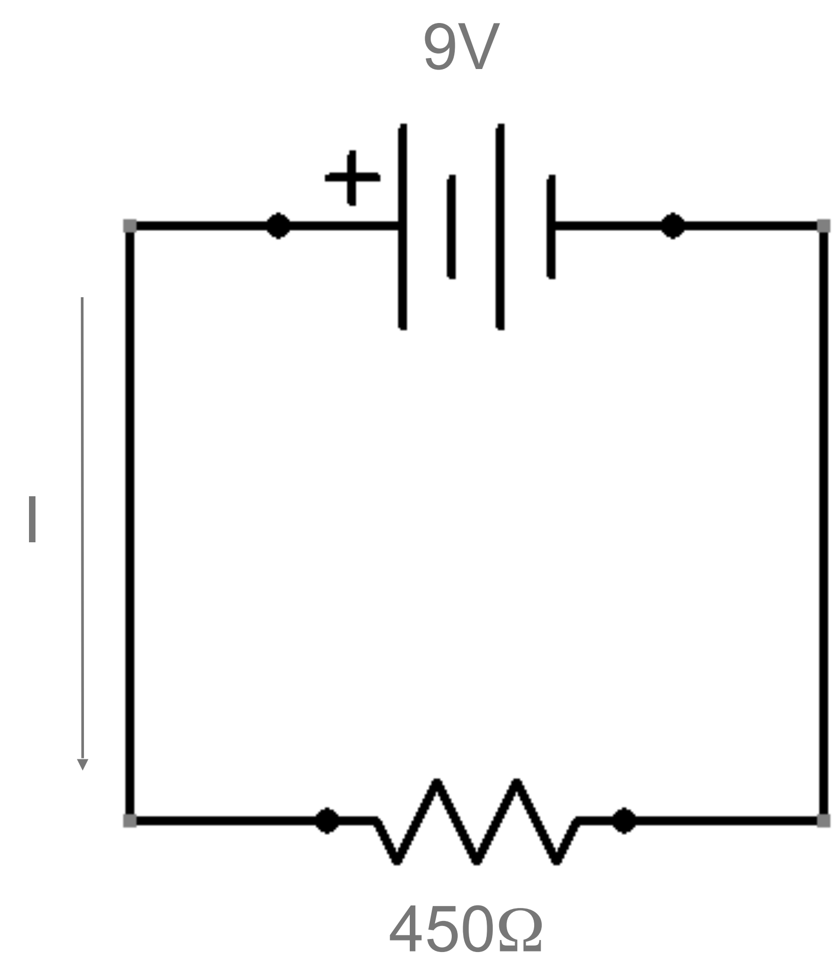
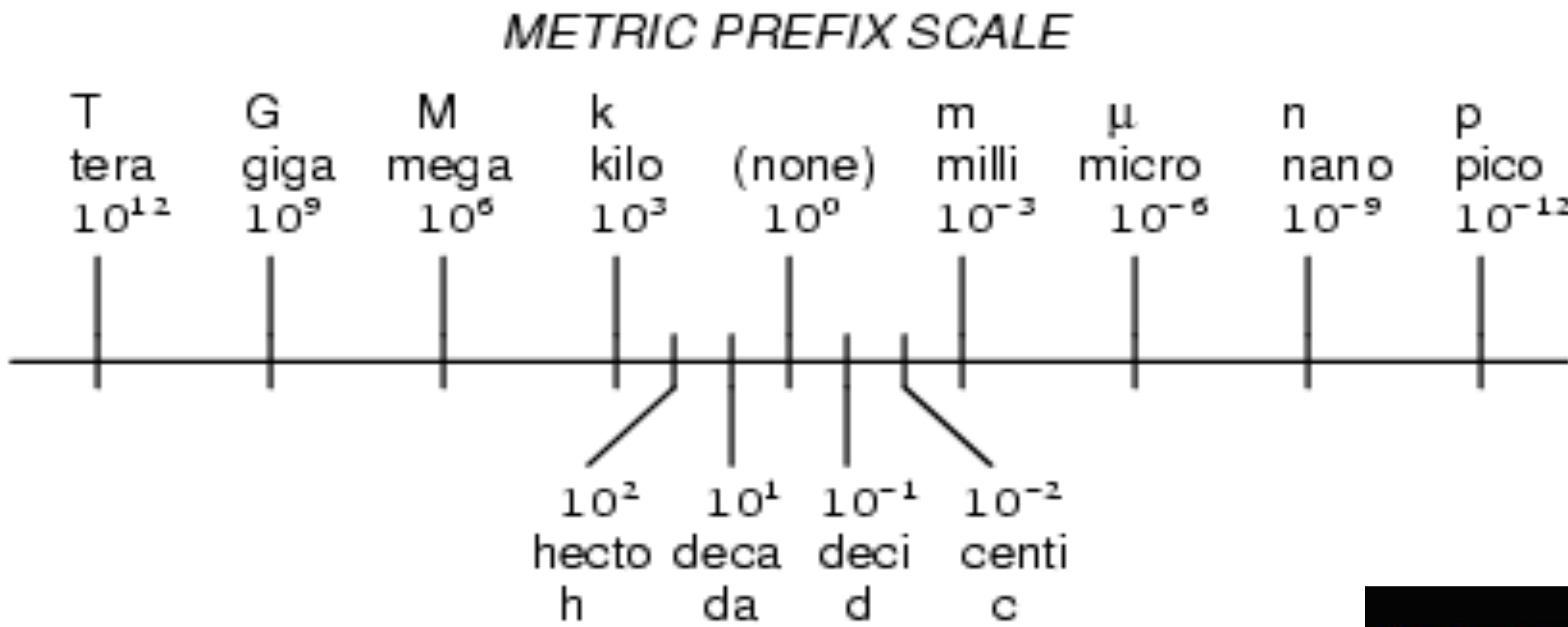
↓

20***m***A (*milli*Amps)



Metric Prefixes



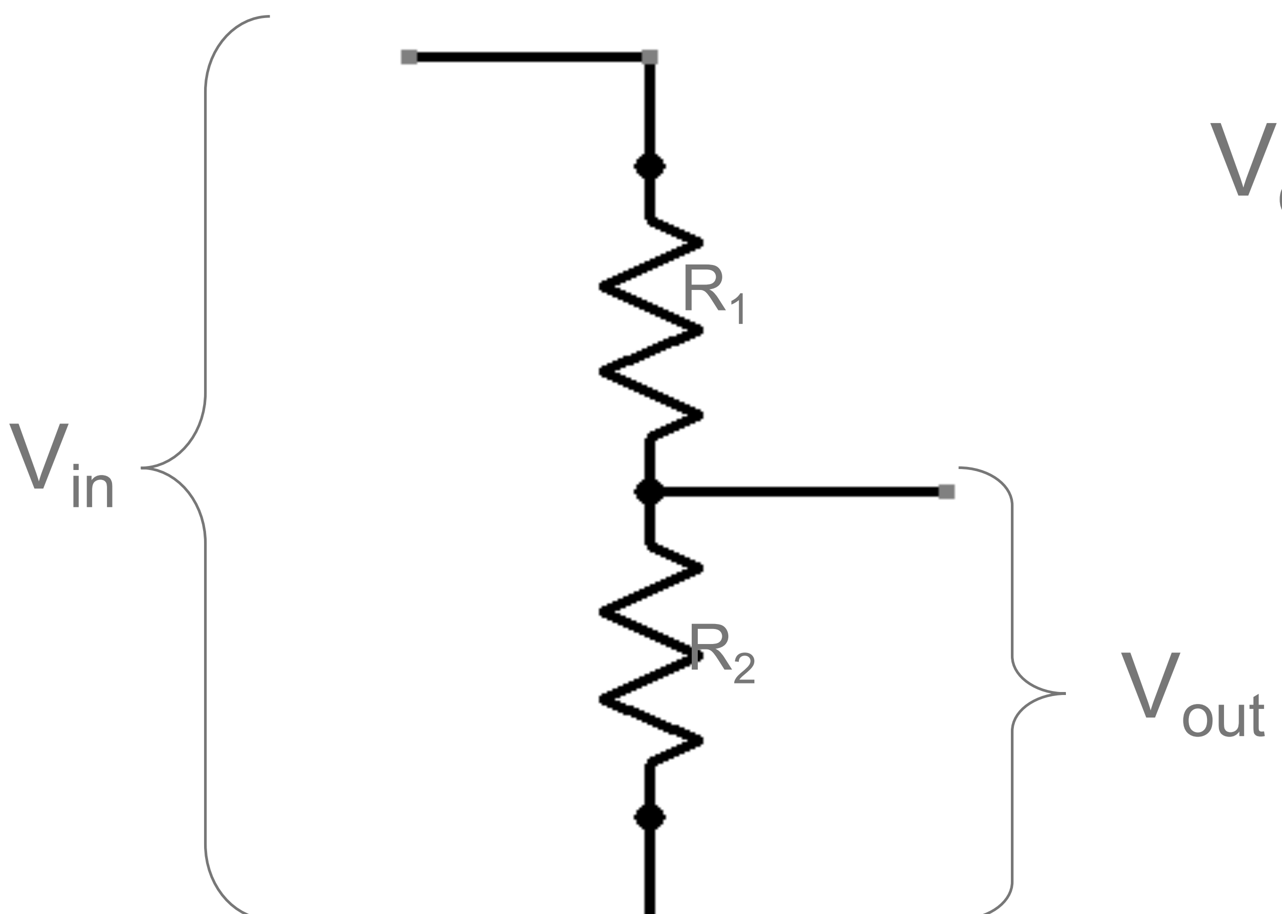
giga = 1,000,000,000
mega = 1,000,000
kilo = 1,000
milli = 0.001
micro = 0.000 001
nano = 0.000 000 001
pico = 0.000 000 000 001

"1.21 Gigawatts!!!"

Lightning is about 120 MV
(power = voltage*current: P = V*I)
Watts = Volts * Amps
1.21GW / 120MV ~= **10 A**

Voltage Dividers

Two resistors in series can create a **voltage divider.** This is a simple way to trim down a higher voltage to a lower desired voltage (e.g. 9v to 5v).



$$V_{out} = V_{in} * R_2/(R_1 + R_2)$$

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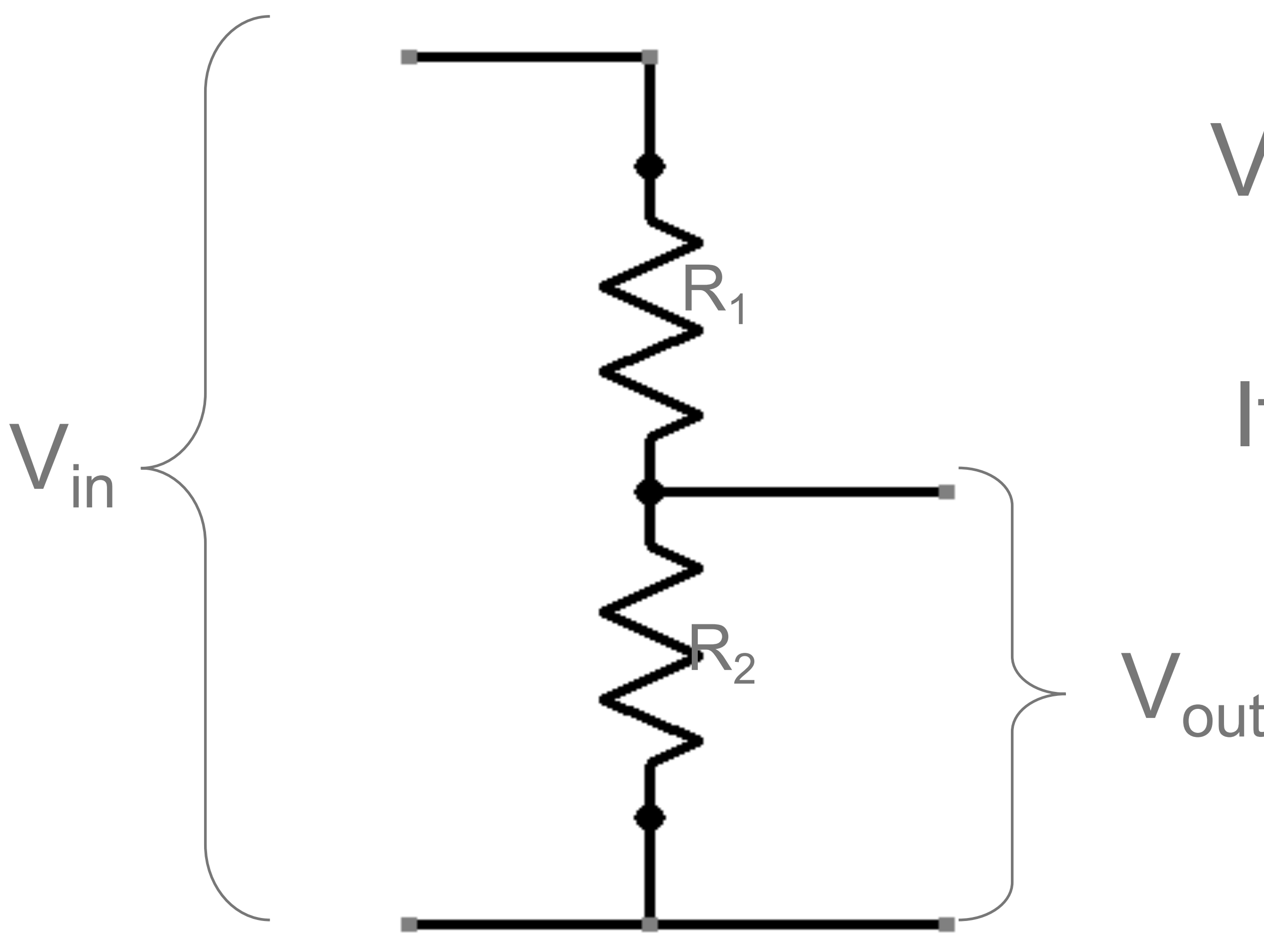


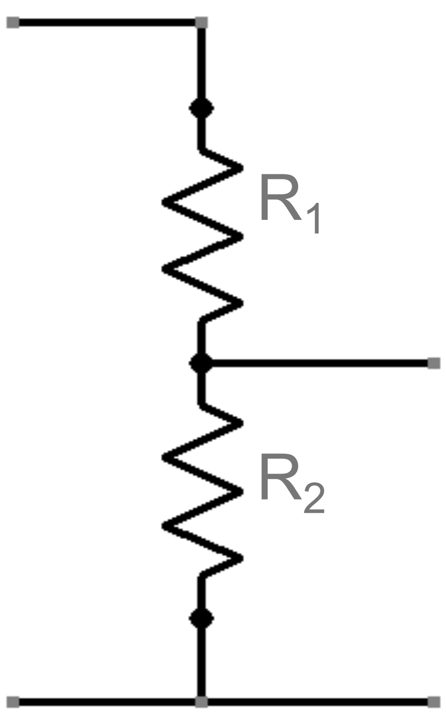
$V_{out} = V_{in} * R_2/(R_1 + R_2)$

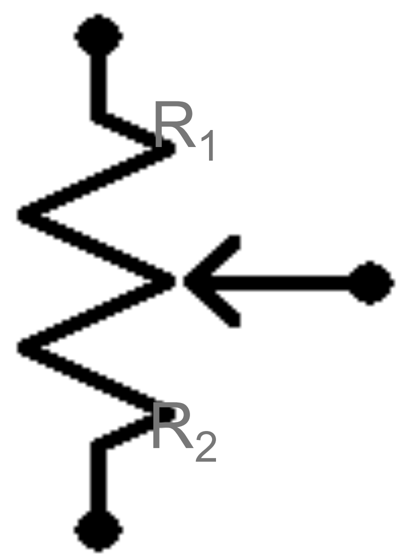
If $R_1 = R_2$, then $V_{out} = V_{in} / 2$

Potentiometer

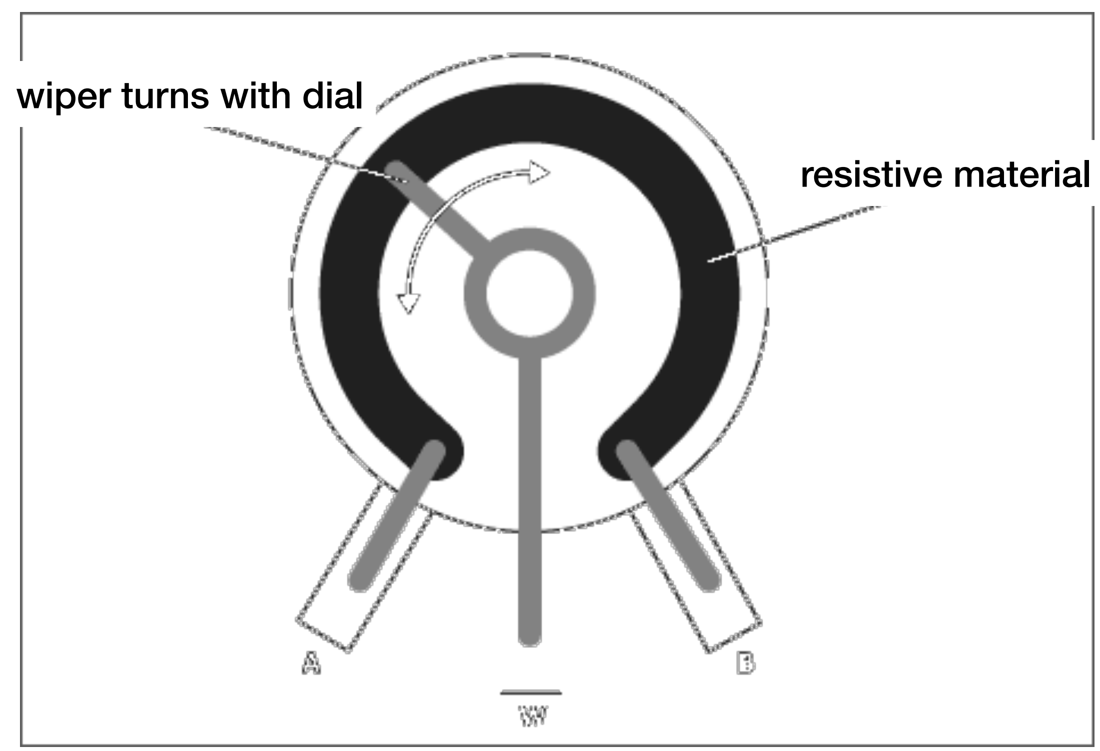
A variable voltage divider packaged up into a single device is called a potentiometer.   It is essentially a resistor with a tap in middle called a wiper.

Very nice property that the size of $R_1 + R_2$ remains constant regardless of wiper position. Which means, V_{out} has a linear relationship with position.





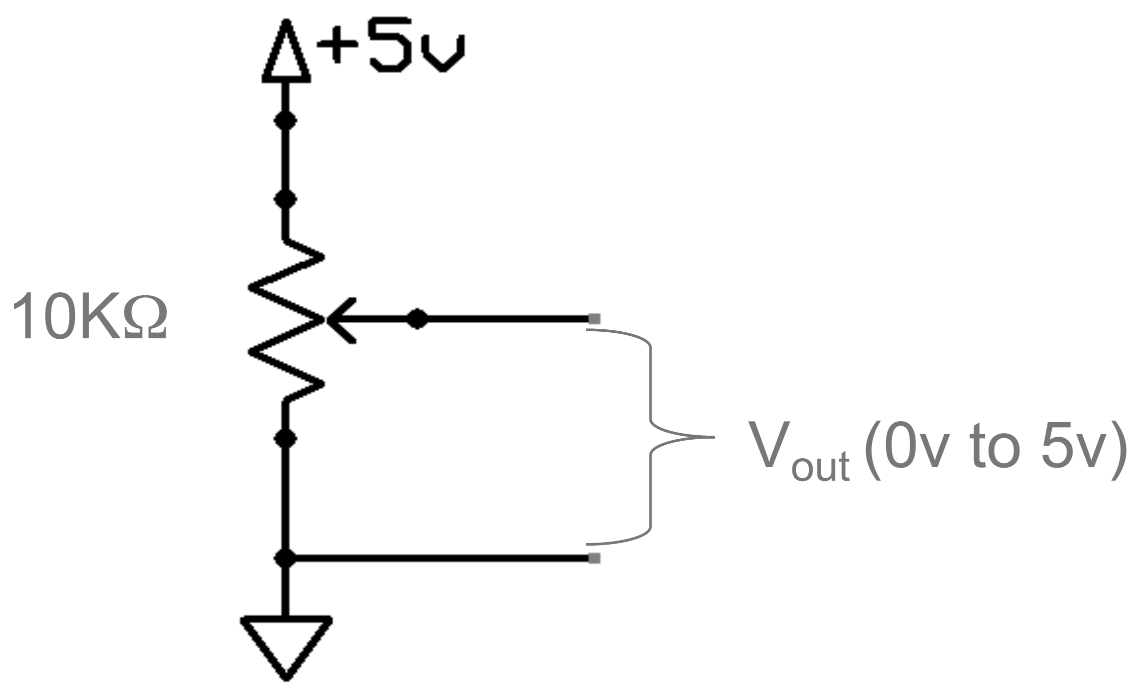
Schematic symbol
For potentiometer

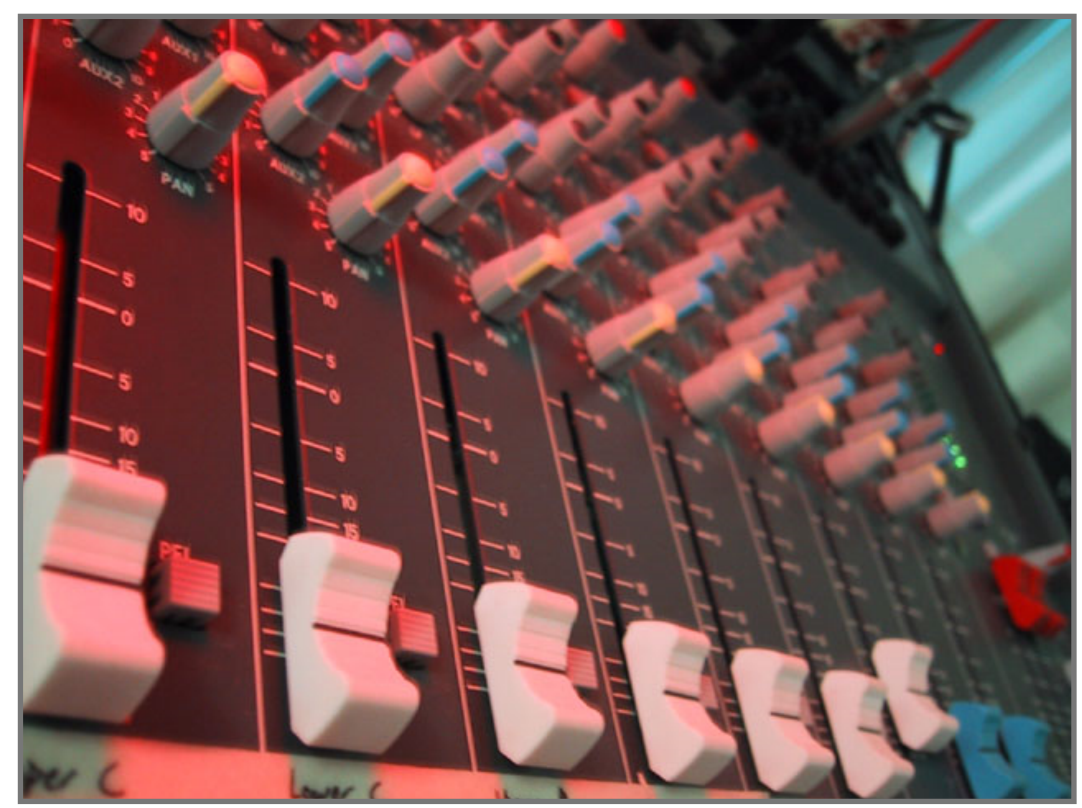


Potentiometers as Input

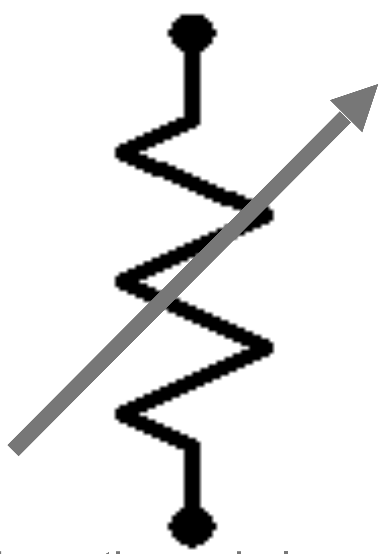
As a result, potentiometers are perfect for analog input devices such as knobs and sliders.

Example Circuit:





Variable Resistors (a.k.a. rheostat)

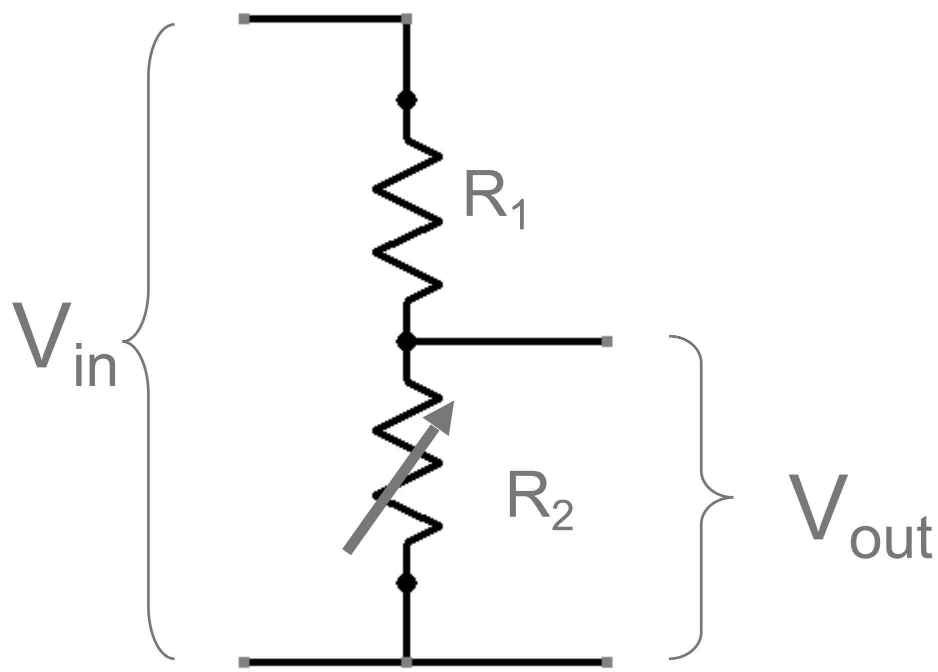


Schematic symbol

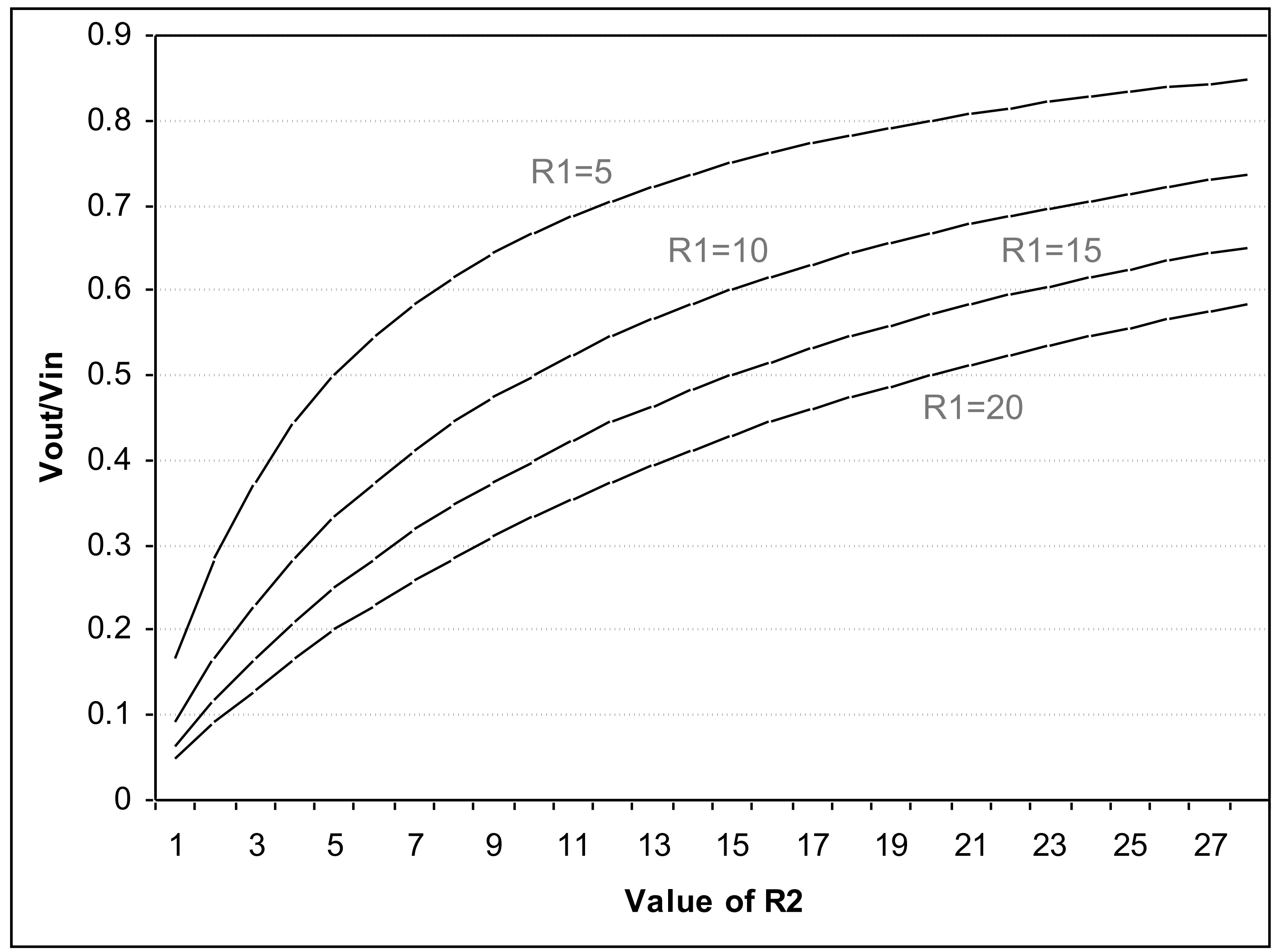
Force Sensor

“Thermistor”
(Temperature sensor)

Using Rheostats



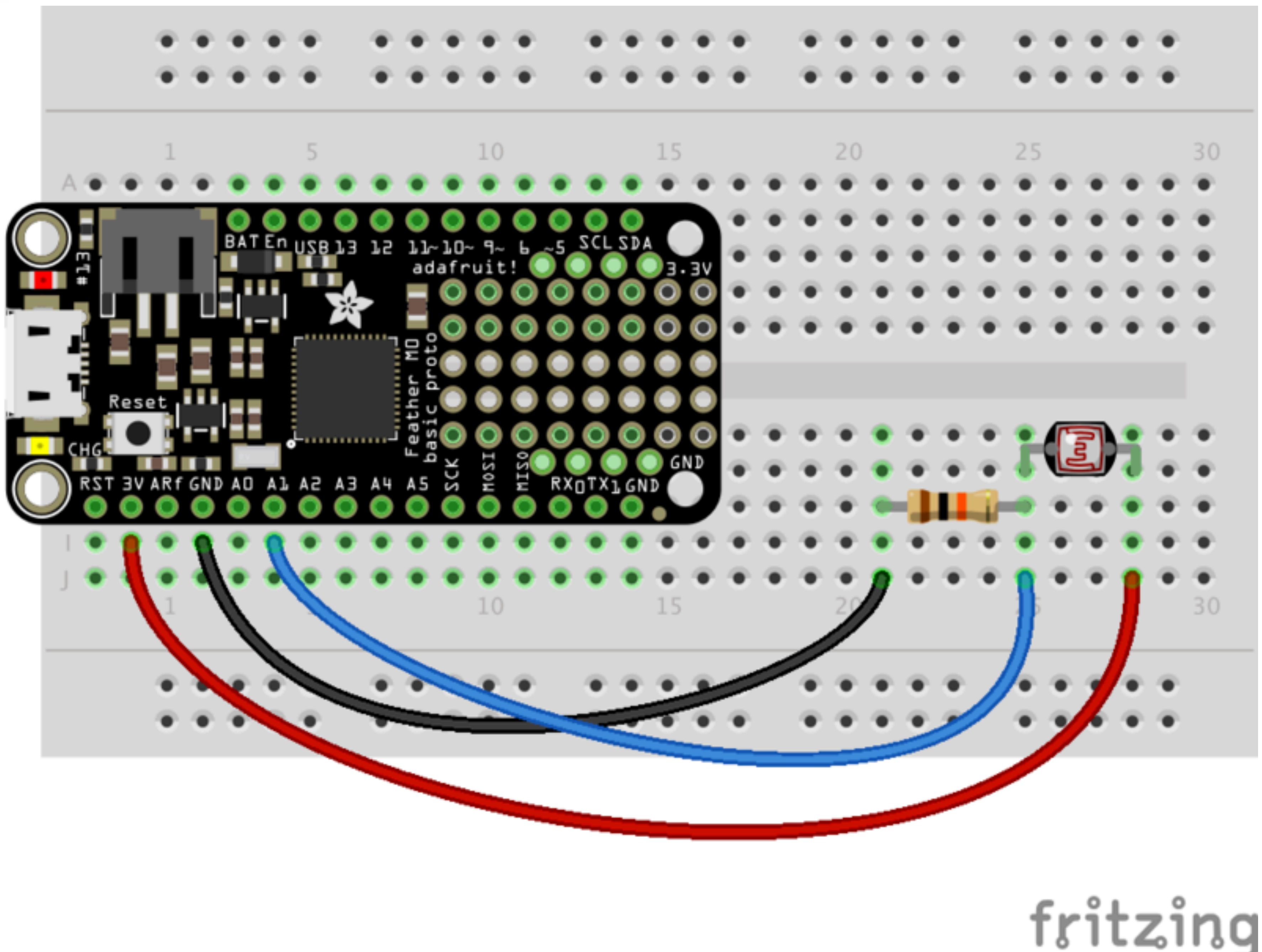
$$V_{out} = V_{in} * R_2/(R_1 + R_2)$$



Variable resistor example

https://learn.adafruit.com/photocells/circuitpython

```
import board
import analogio
photocell = analogio.AnalogIn(board.A1)
photocell.value
```

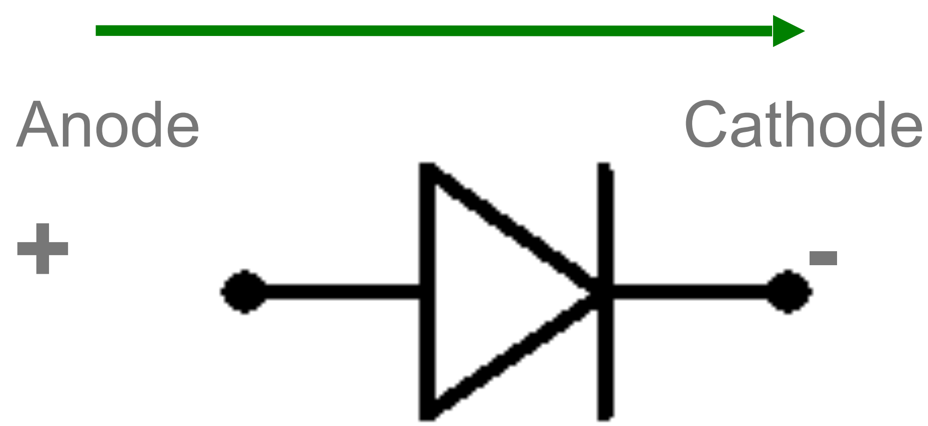


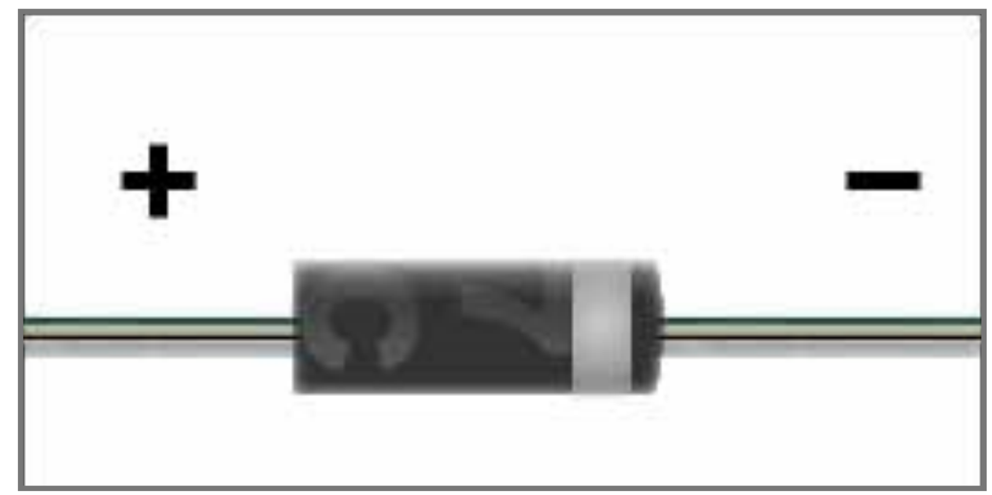
Variable resistors: Practicalities

- try to match your resistor to your variable resistor (10kΩ resistor matched to 10kΩ photocell)
- check the datasheet!
- not directional (doesn’t matter which leg you hook up how)

Diodes

Forward Biased: Current Flow

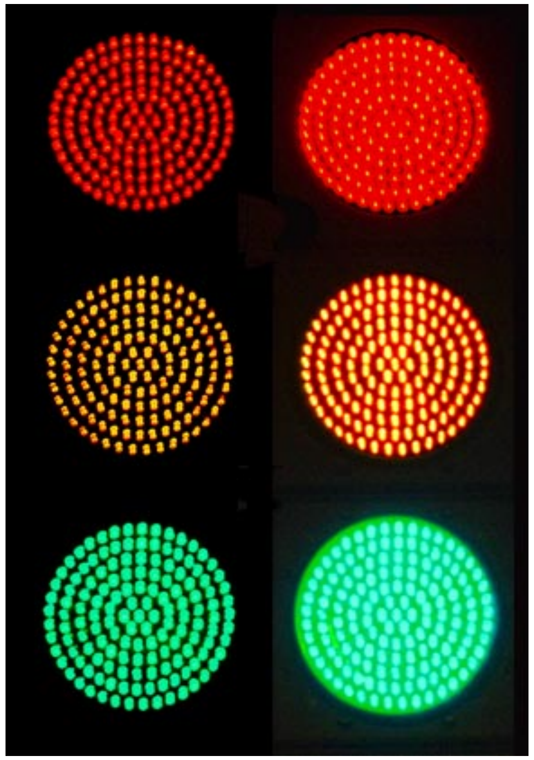


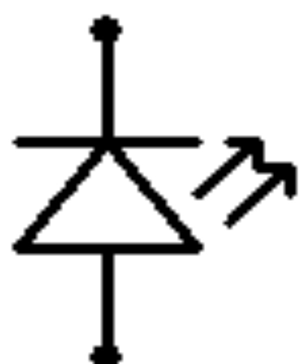


Reverse biased: NO Current Flow

Noteworthy Diodes: LEDs

LED – Light emitting diode, emits light energy when the diode is forward biased. Typically requires 1.5-2.5v to turn on. Typical (max) operating current is 10-50mA.





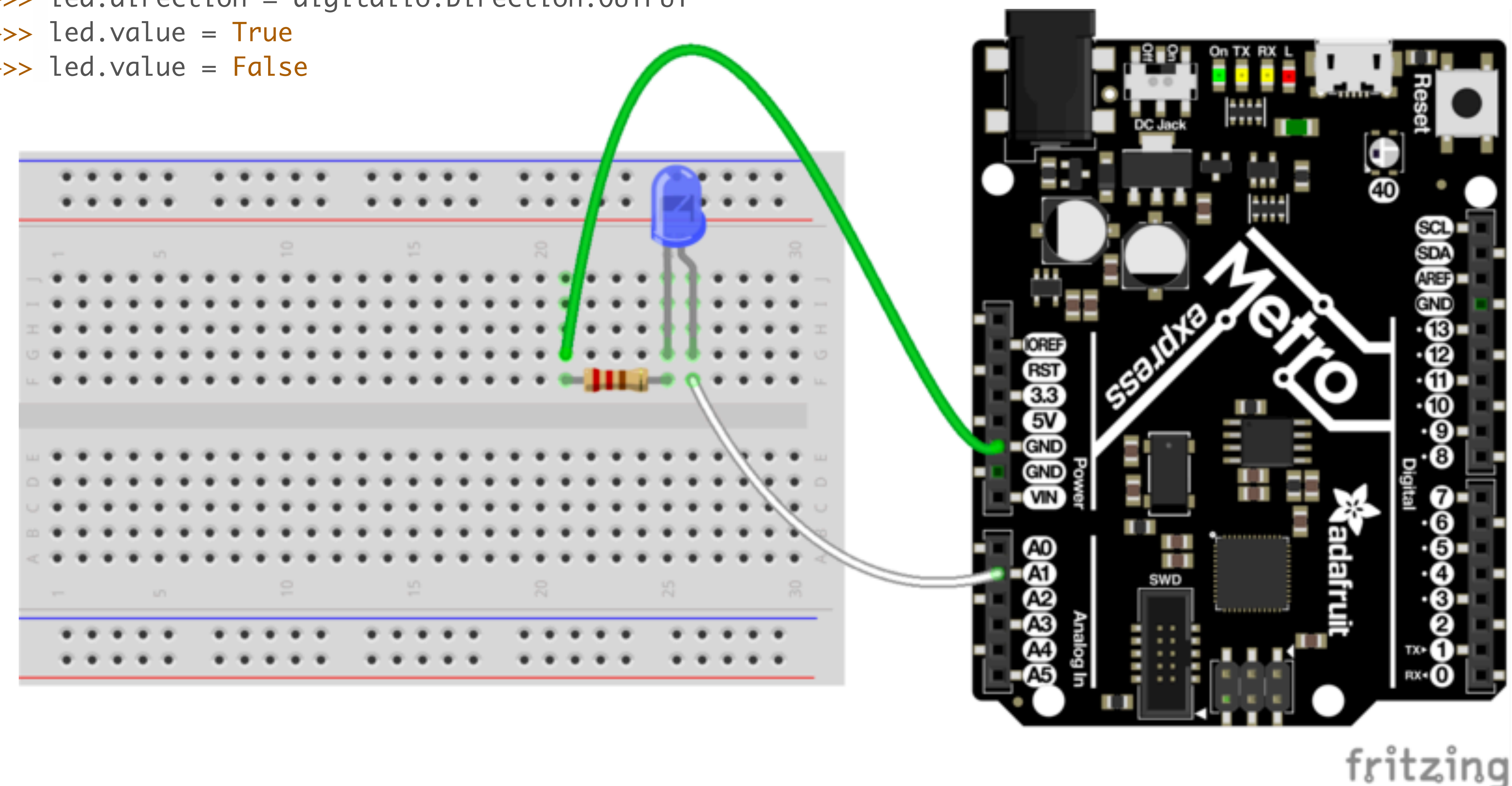
Schematic symbol

Luxeon Star 5 Watt
Turns on at ~6.5V and can be run continuously at nearly 1A, but can be pulsed higher.

LED Example

https://learn.adafruit.com/circuitpython-digital-inputs-and-outputs/digital-outputs

```
>>> import board
>>> import digitalio
>>> led = digitalio.DigitalInOut(board.A1)
>>> led.direction = digitalio.Direction.OUTPUT
>>> led.value = True
>>> led.value = False
```



LEDs: Practicalities

- Diodes are Directional! The leg lengths show you this: short leg goes to ground, long leg goes to power
- Most LEDs use a 330Ω resistor, but if in doubt *check the datasheet*
- We have some IR LEDs around… you can check these out by using your phone’s camera, but your eyes can’t see in IR

Schematic Diagrams

Lines represent conductive paths

e.g., wires or PCB traces

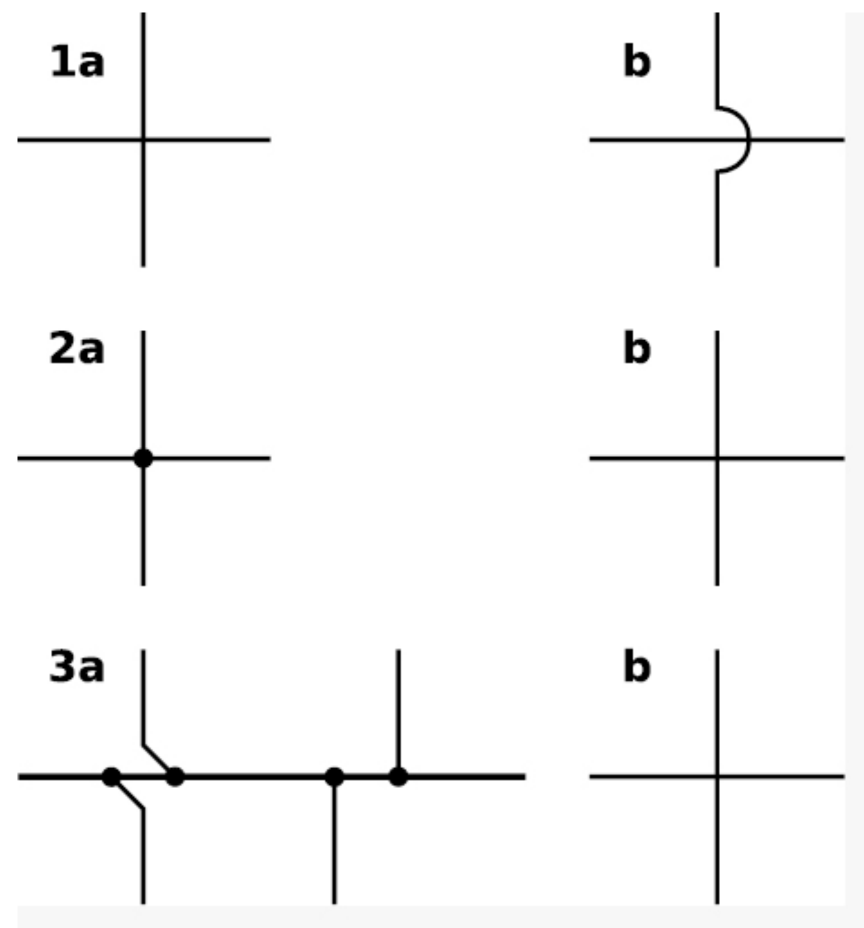
Notation for connections (or lack there of):

Connected | Not Connected

Old Style (Still seen):

"Early CAD" (Typical):

Best Practice:



Schematic Diagrams

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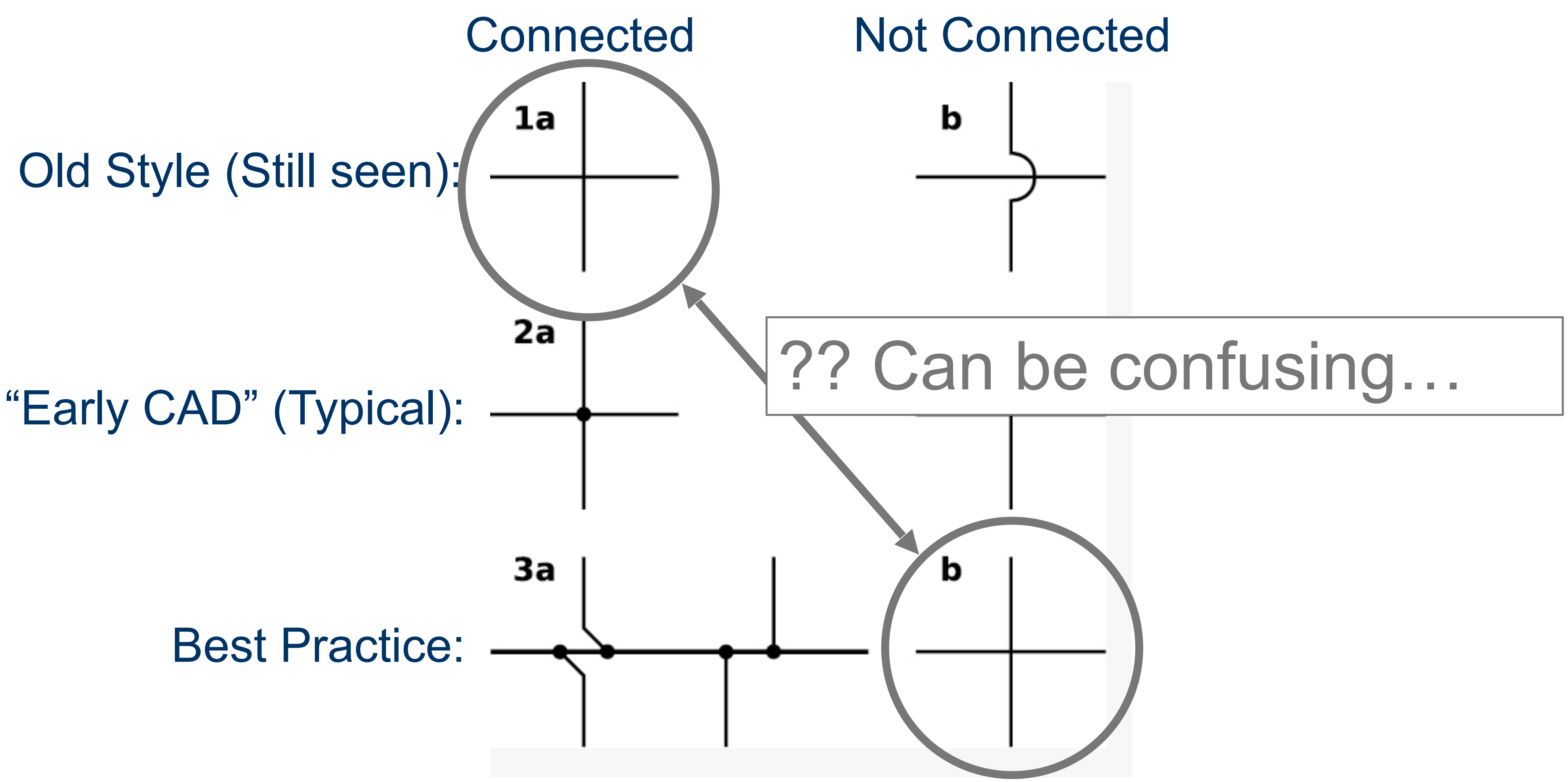
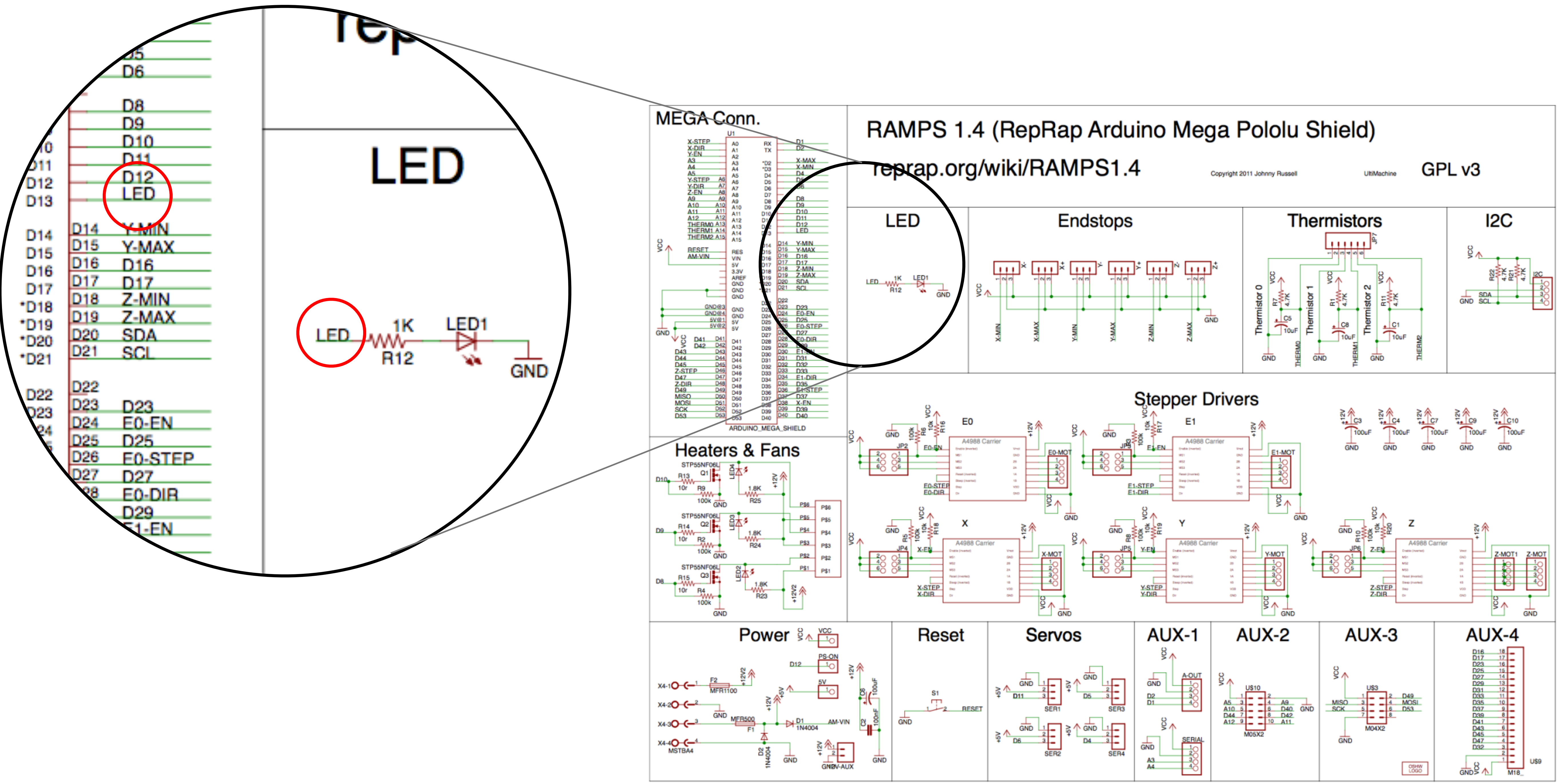


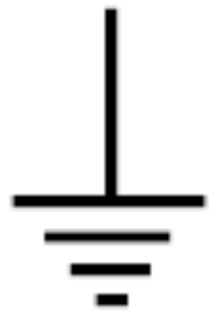
Schematic Diagrams

You will also sometimes see things connected by matching text labels (only)

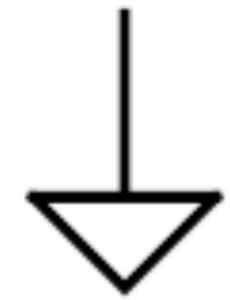


Symbols: Power and Ground

Ground:

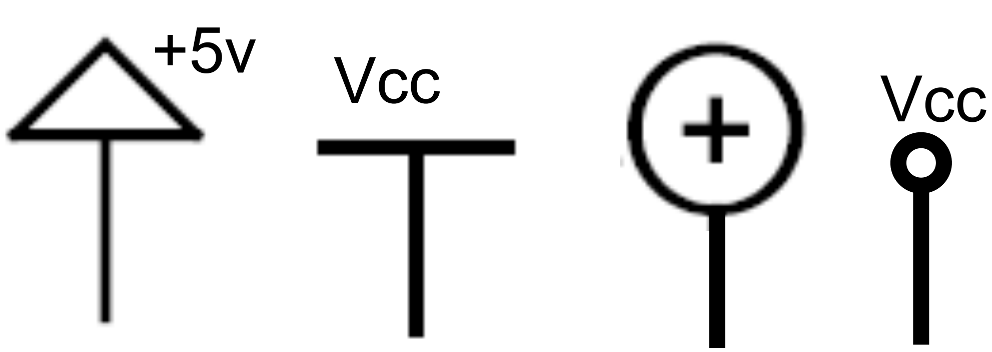


Also:



Occasionally:

Positive Power Supply:

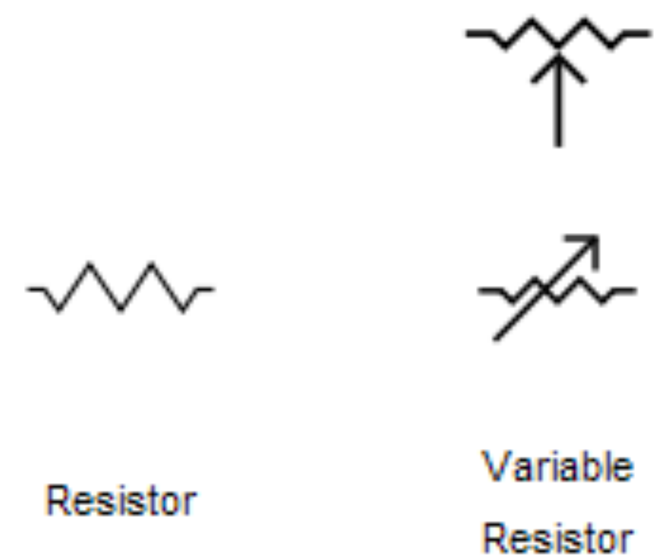


Typical digital circuits run at 5v or 3.3v

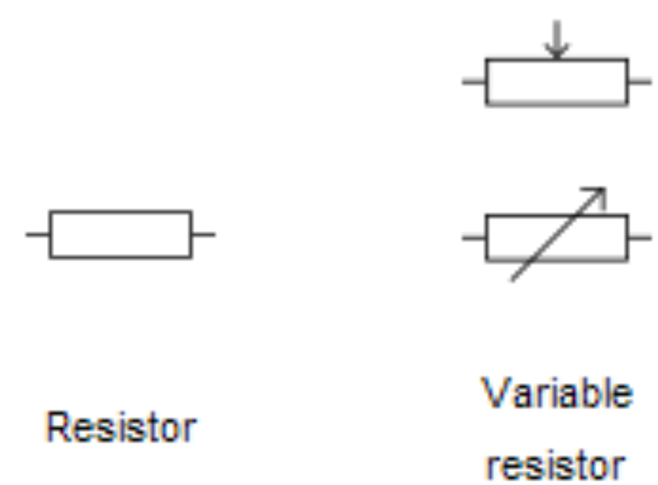
Vcc often used to denote positive supply w/o specifying voltage

Symbols: Resistors

(As we have seen already):

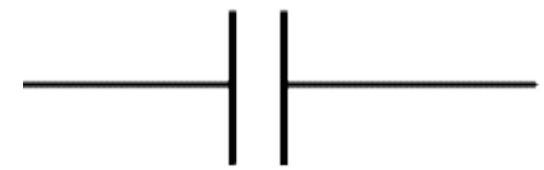


Also drawn as (European style):

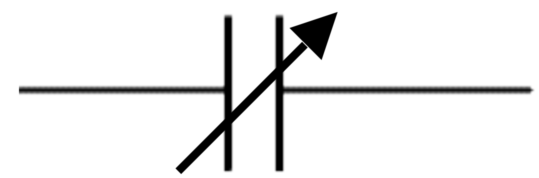


Symbols: Capacitor

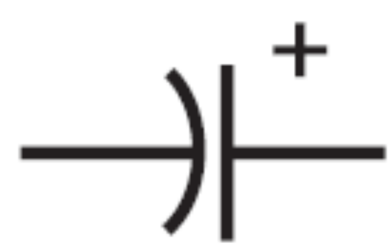
Simple (fixed):



Variable:



Electrolytic (polarized):



What’s a Capacitor?

Something that has “capacitance”…
(not very helpful…)

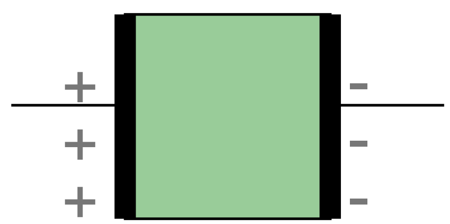
What’s a Capacitor?

Something that has “capacitance”…

Capacitance is basically an ability (capacity) to hold a charge

Capacitance

To “hold a charge” we use a device with two conducting plates separated by insulating material (called dielectric)



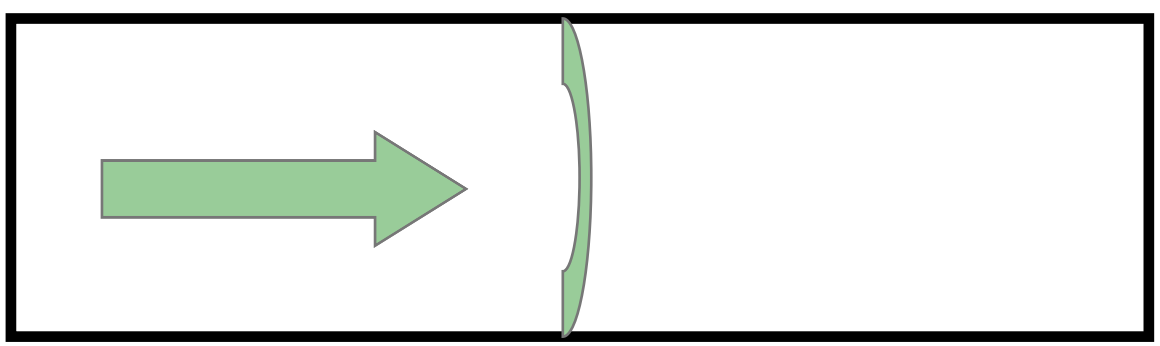
- + and – charge on two sides in close proximity are attracted (and held there by the resulting force), but can’t easily flow across insulator

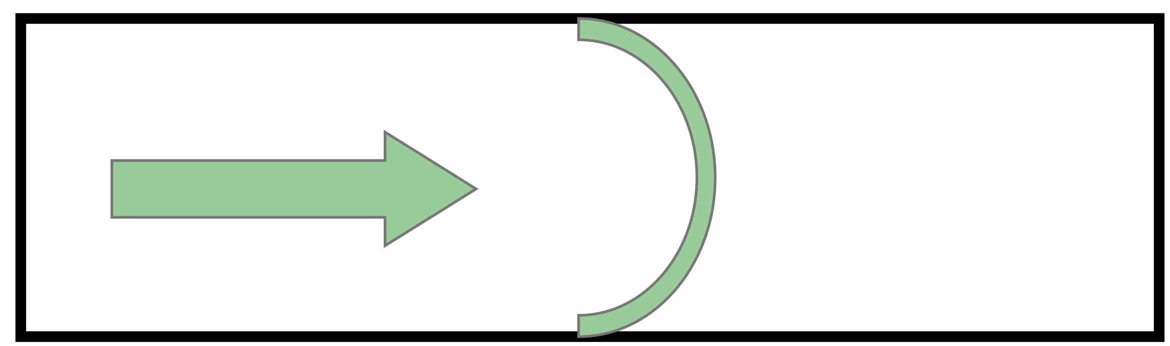
→Stores electric charge

Capacitance

Water analogy

- Consider a pipe with a rubber balloon blocking it
- Charge can flow in, expanding the balloon
  - This stores a charge
  - But only so far – can't get a steady flow past the balloon



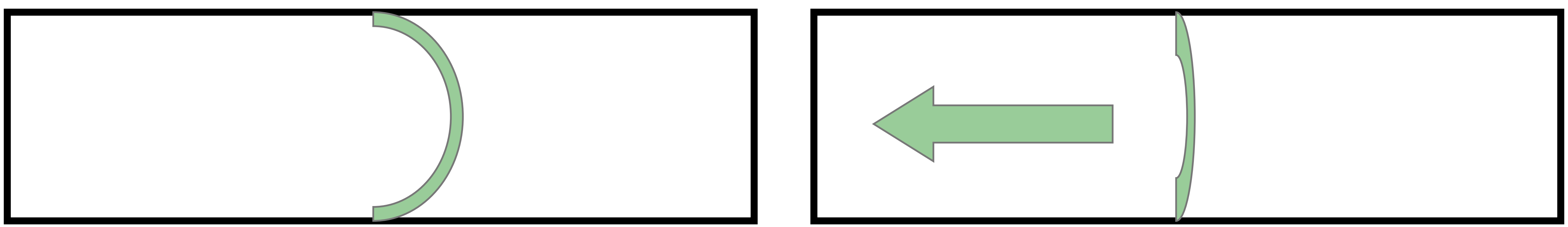


Capacitance

Water analogy

- Consider a pipe with a rubber balloon blocking it
- Charge can flow in, expanding the balloon
  - This stores a charge
  - But only so far – can't get a steady flow past the balloon

  - Release the flow and water stored in expanded balloon flows back



  - Storing and releasing charge like a little battery

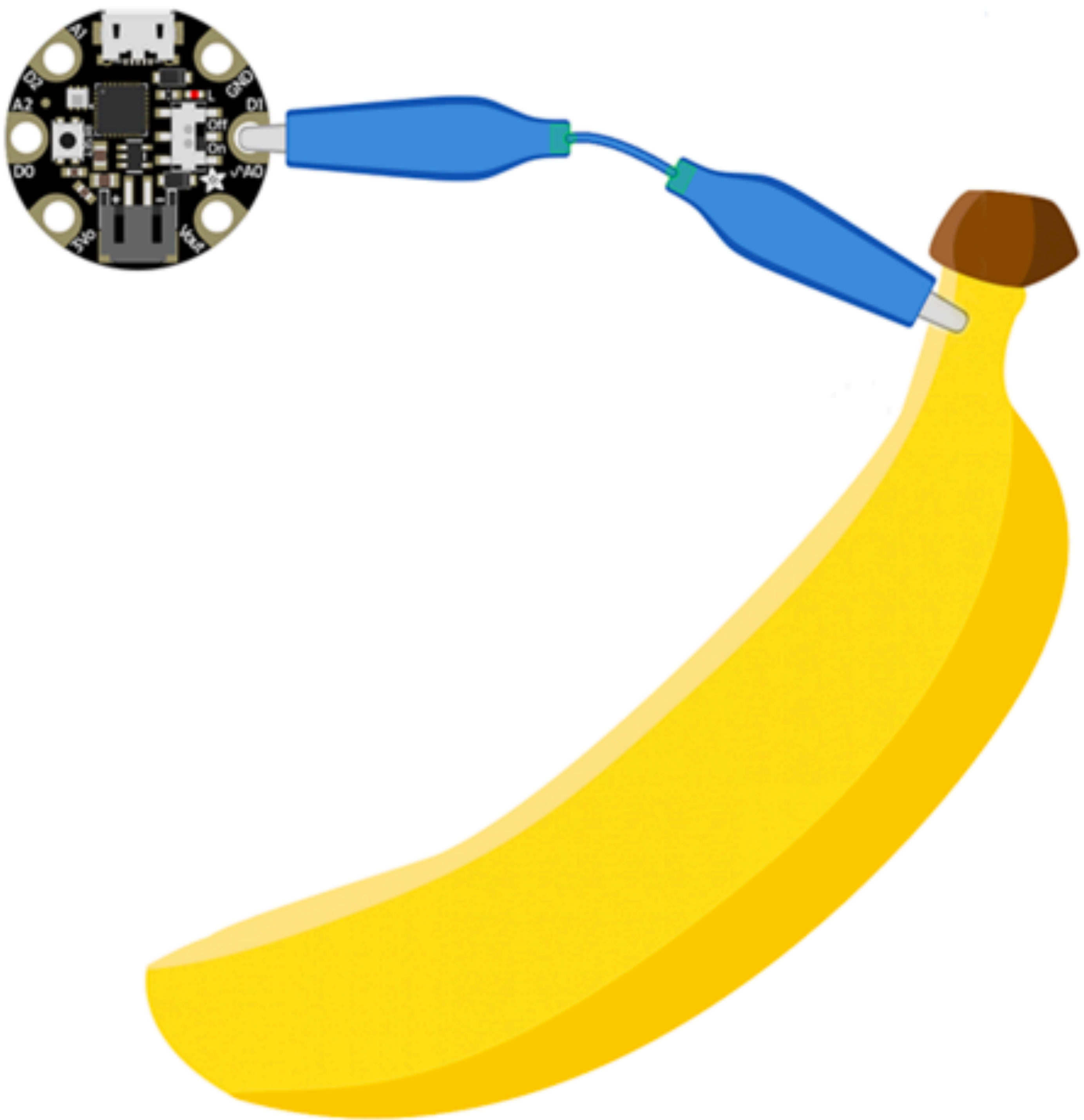
Capacitance

Another interesting thing happens when the charge moves back and forth…

Capacitive Sensing Example

https://learn.adafruit.com/circuitpython-essentials/circuitpython-cap-touch

```
import board
import time
import touchio

touch_pad = board.A0
touch = touchio.TouchIn(touch_pad)

while True:
    if touch.value:
        print("Touched!")
    time.sleep(0.05)
```



Capacitive Sensing: Practicalities

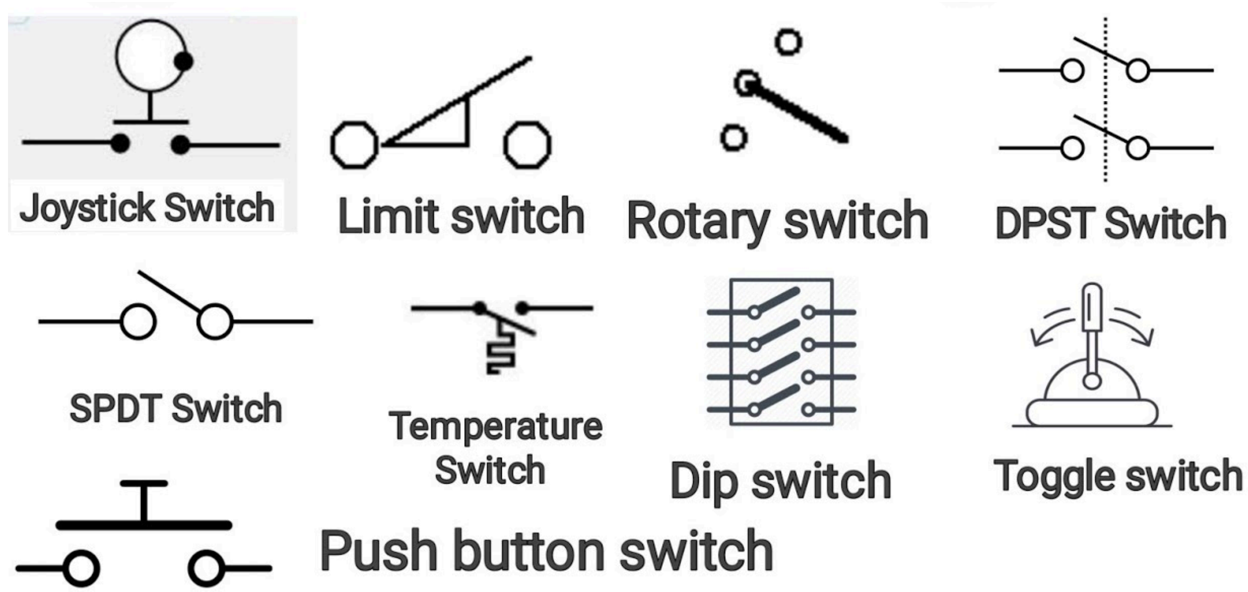
- you can use almost anything as a touchpad, as long as it’s conductive (we have copper tape, some work uses plants, …)
- at a lower level, you can also see touch pressure

```
import board
import touchio

touch_pad = board.A0
touch = touchio.TouchIn(touch_pad)

while True:
    print(touch.raw_value)
```

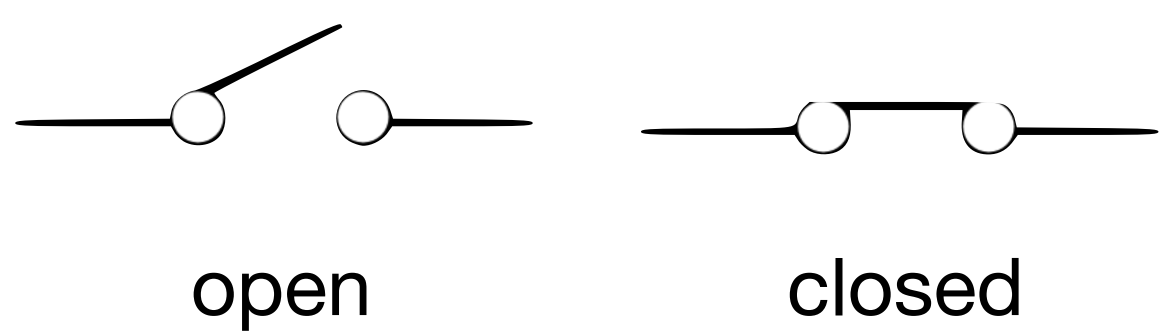
- what you’re actually measuring is the time it takes to create that charge

Symbols: Switches

Lots of kinds of switches…



You probably only need to know the generic switch symbols:



Switches Example

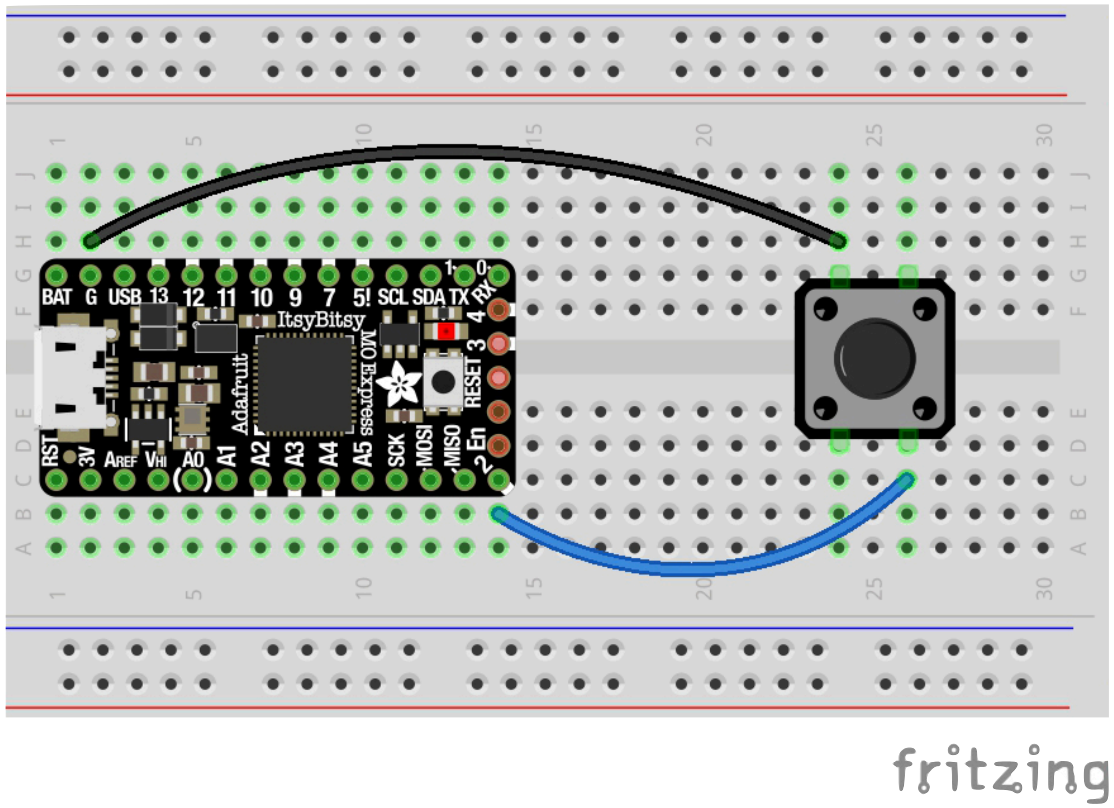
https://learn.adafruit.com/circuitpython-essentials/circuitpython-digital-in-out

```python
import time
import board
from digitalio import DigitalInOut, Direction, Pull

led = DigitalInOut(board.D13) # we don’t have board.LED
led.direction = Direction.OUTPUT

switch = DigitalInOut(board.D2)
switch.direction = Direction.INPUT
switch.pull = Pull.UP

while True:
    led.value = not switch.value
    time.sleep(0.01)  # debounce delay
```



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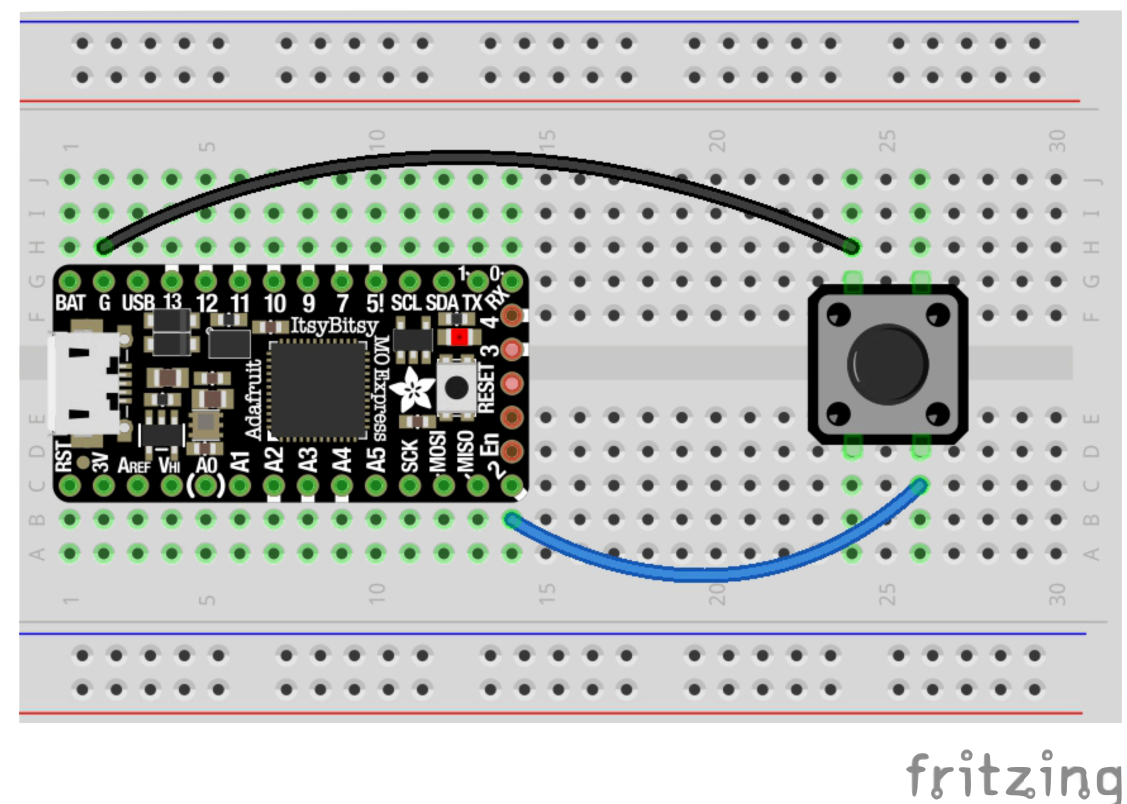
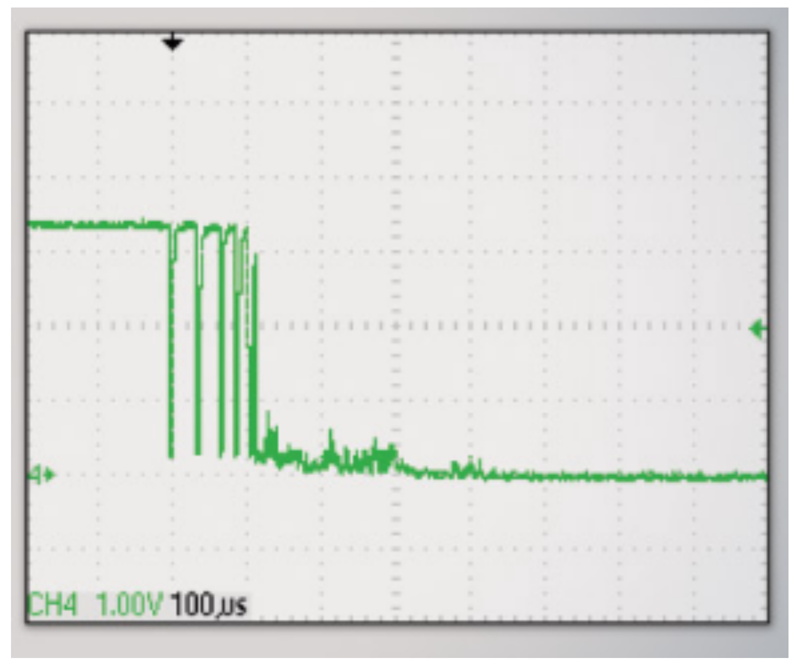
```

??????



Switches: Practicalities

- Switches “bounce”. You need to “debounce” them. This can be done by waiting, by smoothing, or by something fancier.



- Consider “debouncing” before kicking off big work!

Symbols: Transistors

Transistors come in a number of forms

- Simplest: NPN and PNP
  (names come from layers of positive and negative "doped" semiconductor material)

NPN:

PNP:

Symbols: Transistors

Transistors come in a number of forms

- Simplest: NPN and PNP
  (names come from layers of positive and negative “doped” semiconductor material)

NPN:

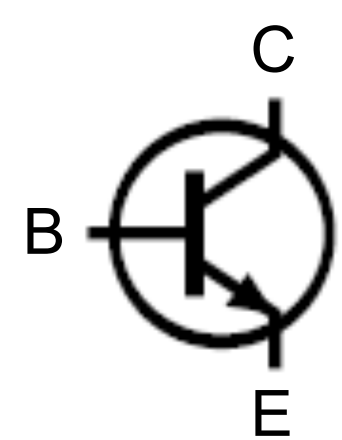
PNP:

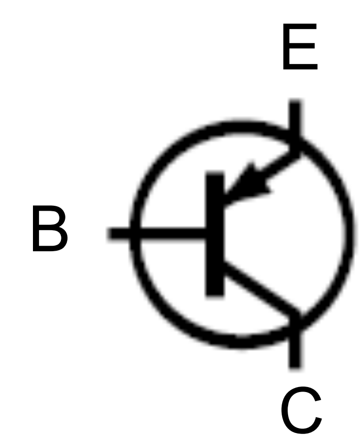
Connections are:

Base

Collector

Emitter

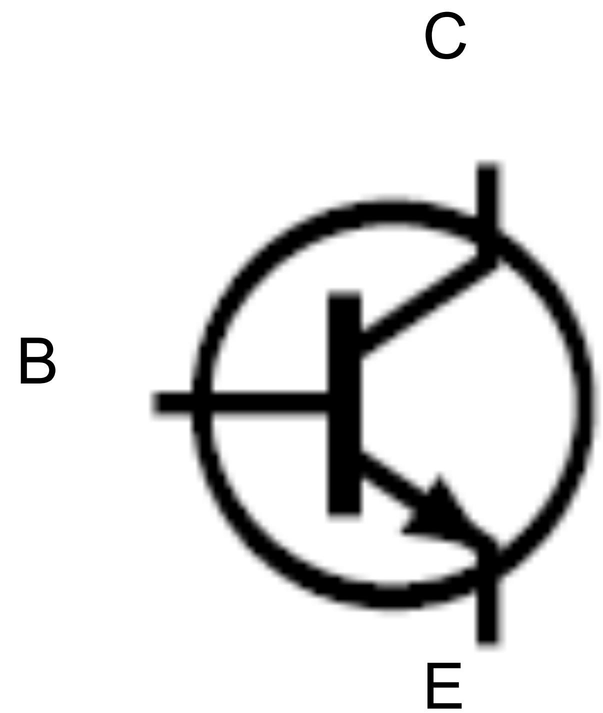




What are transistors?

Amplifiers

Small current on Base allows large current to flow between Collector and Emitter



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Amplifiers

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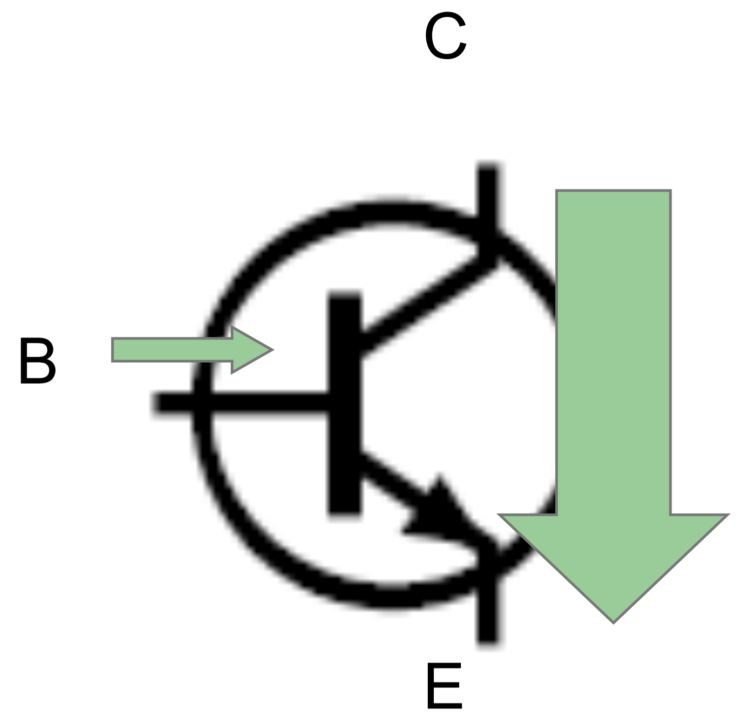
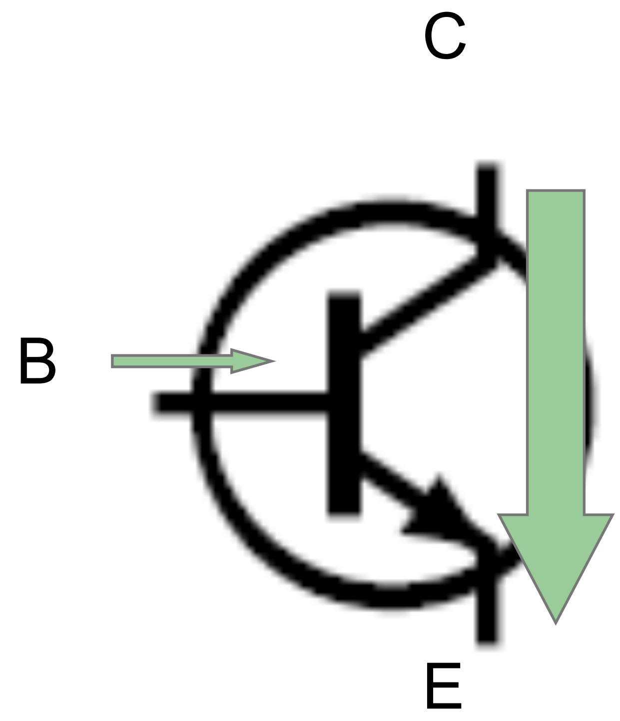


What are transistors?

Amplifiers

Small current on Base allows large current to flow between Collector and Emitter

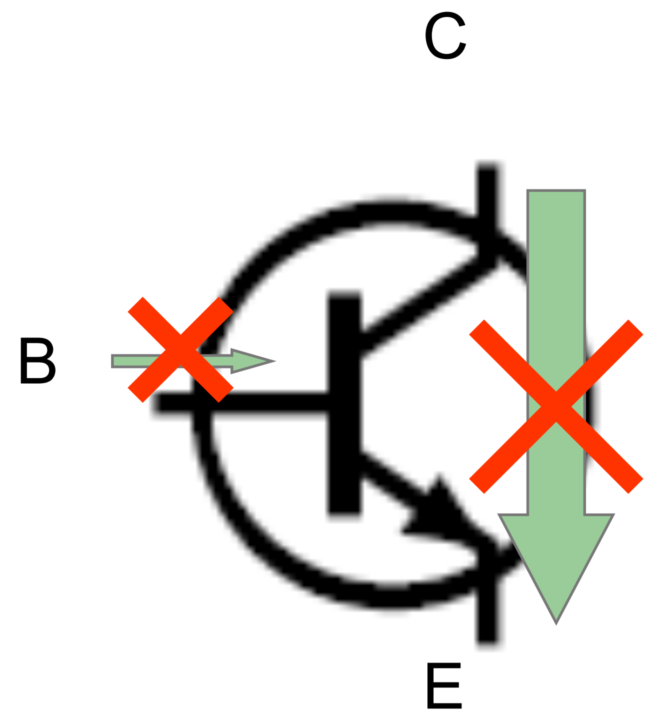


Reduce current on Base, C→E flow is reduced

What are transistors?

Amplifiers

Small current on Base allows large current to flow between Collector and Emitter

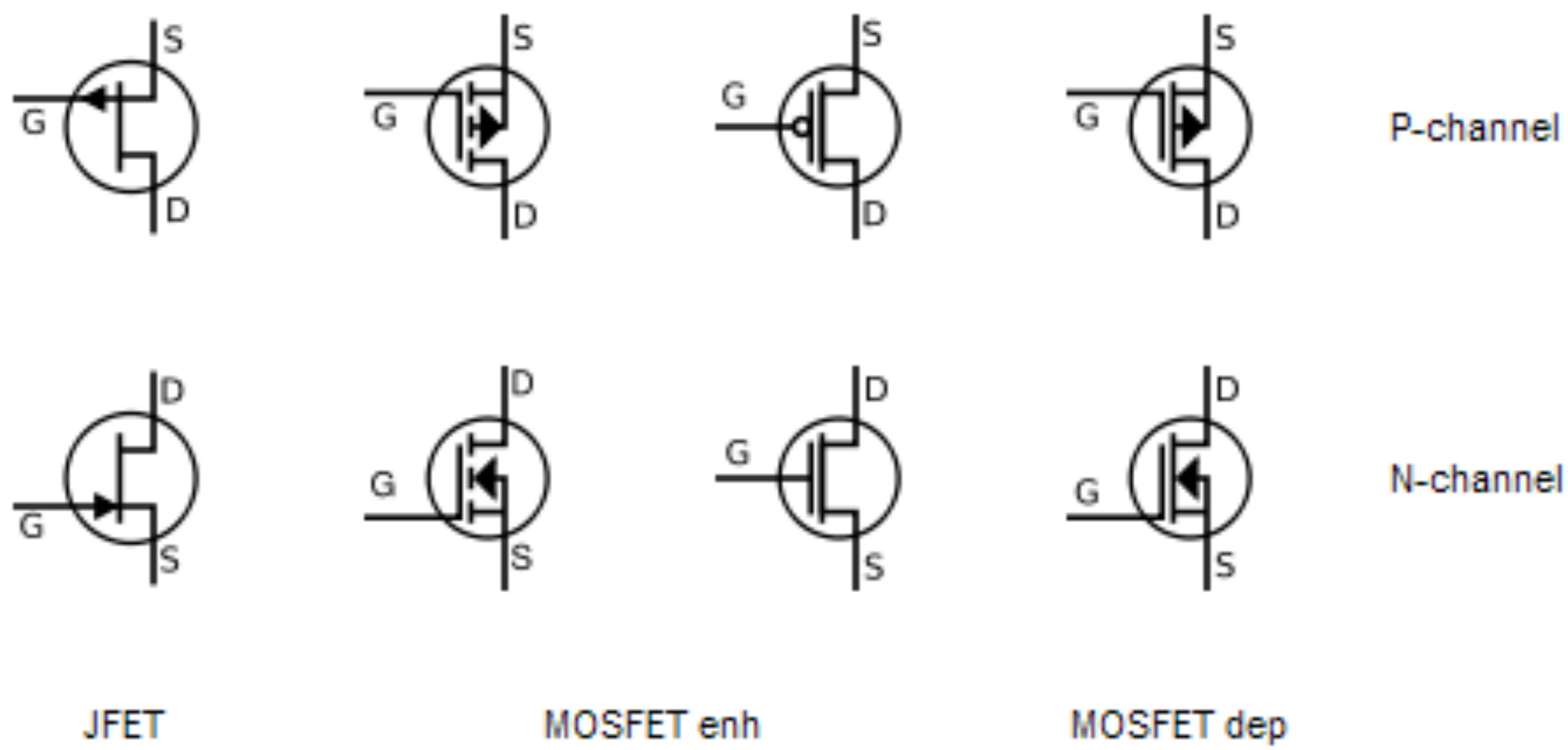


Eliminate current on Base, C→E flow is eliminated

Symbols: Other Kinds of Transistors

Common (NPN & PNP) are "Bipolar"

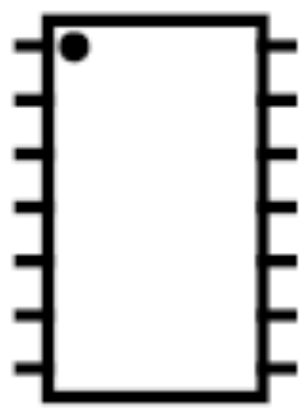
Several other types:
… including various types of Field Effect Transistors (FET)



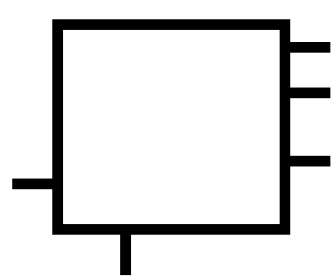
Symbols

Integrated circuits (ICs)

- Represented by boxes with lines coming out
- Sometimes matching physical pins



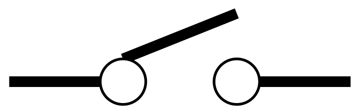
- Often not (pins placed as convenient to diagram layout):



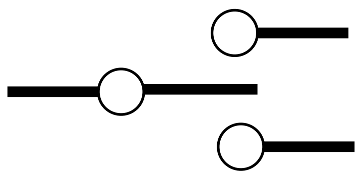
More Symbols

Switches:

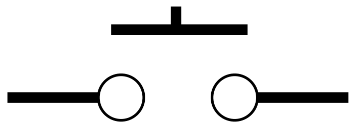
Single pole single throw (SPST):



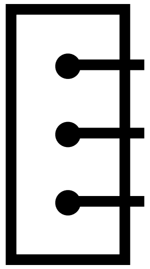
Single pole double throw (SPDT):



Normally Open (push button):



Jumpers or connectors (“header pins”):



More Symbols

Crystal
(or Piezo element):

Fuse:

Inductor (coil, coke):

Transformer:

Speaker:

Antenna:

or

And many more…

Labeling

Typically give a value for the component

45Ω or $0.1\mu F$

Sometimes see special notation for resistor values:

1R4	Meaning:	Resistor: $1.0\text{x}10^{4} = 10\text{K}\Omega$
47R1	Meaning:	Resistor: $47\text{x}10^{1} = 470\Omega$

For ICs, transistors, etc. often give component num

e.g. NPN transistor: 2N2222

e.g., PSoC chip: CY8C29466

Labeling

Generally label with a component "name"

e.g., C5, R16, D3, U1, T9

Letter gives type:

C – Capacitor

R – Resistor

D – Diode

T – Transistor

J – Jumper or "Jack" (connector)

L – Inductor (coil, choke) ["Loop"]

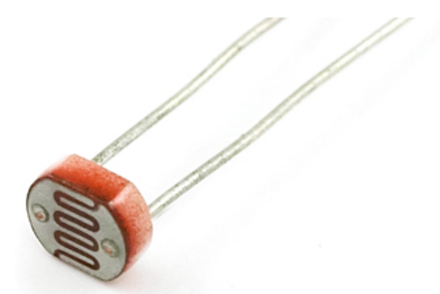
U – IC

Identifying parts by sight

Resistors:

Capacitors:

Photocell / photo-resistor:



Potentiometer:

Identifying parts by sight

Tilt switch:

Thermistor:

Tact(ile) switch:

LED:

8x8 LED matrix:

Identifying parts by sight

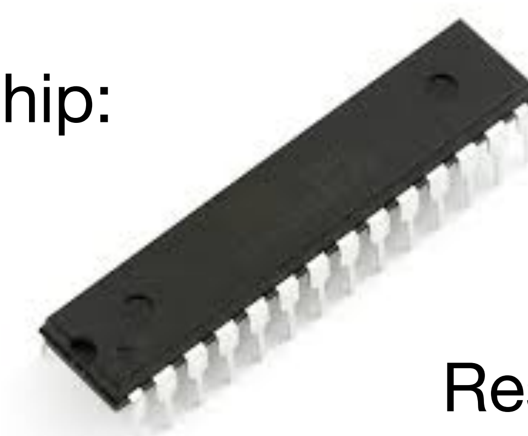
Note: Various kinds of both transistors and voltage regulators share the same forms of package.

NPN transistor

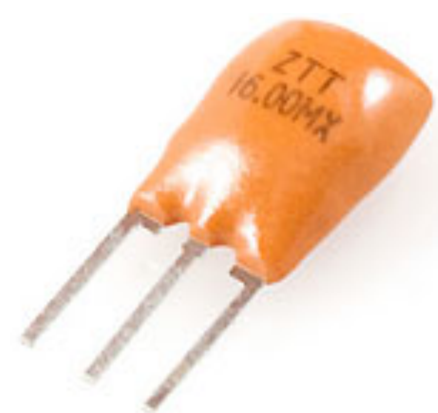
Voltage regulator:

Servo motor:

ATMEGA 328P chip:



Resonator:



Reading Datasheets

- example: https://cdn.sparkfun.com/datasheets/Sensors/Proximity/HCSR04.pdf

Ultrasonic Ranging Module HC - SR04

Product features:

Ultrasonic ranging module HC - SR04 provides 2cm - 400cm non-contact measurement function, the ranging accuracy can reach to 3mm. The modules includes ultrasonic transmitters, receiver and control circuit. The basic principle of work:
(1) Using IO trigger for at least 10us high level signal,
(2) The Module automatically sends eight 40 kHz and detect whether there is a pulse signal back.
(3) IF the signal back, through high level , time of high output IO duration is the time from sending ultrasonic to returning.
Test distance = (high level time×velocity of sound (340M/S) / 2,

Wire connecting direct as following:

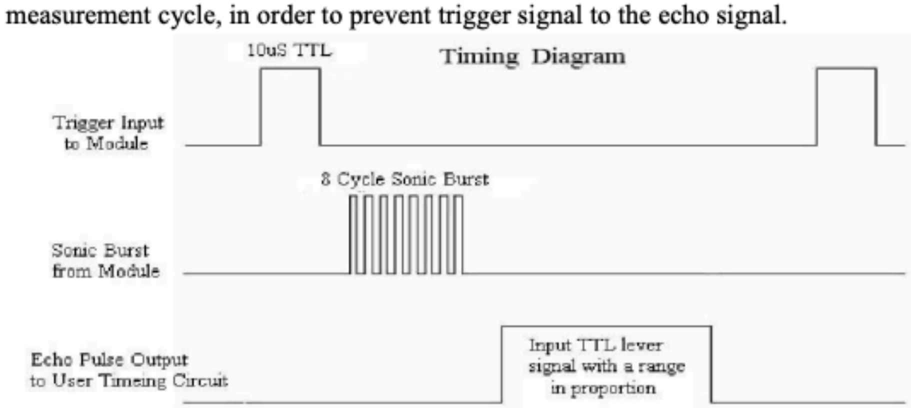
- 5V Supply
- Trigger Pulse Input
- Echo Pulse Output
- 0V Ground

Electric Parameter

Working Voltage	**DC 5 V**
Working Current	**15mA**
Working Frequency	**40Hz**
Max Range	**4m**
Min Range	**2cm**
MeasuringAngle	**15 degree**
Trigger Input Signal	**10uS TTL pulse**
Echo Output Signal	**Input TTL lever signal and the range in proportion**
Dimension	**45*20*15mm**

Timing diagram

The Timing diagram is shown below. You only need to supply a short 10uS pulse to the trigger input to start the ranging, and then the module will send out an 8 cycle burst of ultrasound at 40 kHz and raise its echo. The Echo is a distance object that is pulse width and the range in proportion .You can calculate the range through the time interval between sending trigger signal and receiving echo signal. Formula: uS / 58 = centimeters or uS / 148 =inch; or: the range = high level time * velocity (340M/S) / 2; we suggest to use over 60ms measurement cycle, in order to prevent trigger signal to the echo signal.



Reading Datasheets

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Ultrasonic Ranging Module HC - SR04

how to wire

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Test distance = (high level time×velocity of sound (340M/S) / 2,

Wire connecting direct as following:

how to code

- 5V Supply
- Trigger Pulse Input
- Echo Pulse Output
- 0V Ground

needs: is it compatible with Teensy?

Electric Parameter

Working Voltage	DC 5 V
Working Current	15mA
Working Frequency	40Hz
Max Range	4m
Min Range	2cm
MeasuringAngle	15 degree
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Echo Output Signal	Input TTL lever signal and the range in proportion
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