Diodes and Switches and Breadboards, Oh, My!

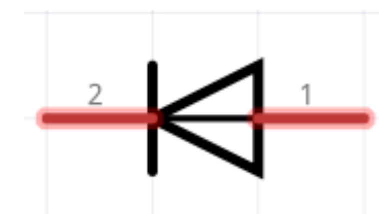
44-440/640-IoT

Objectives

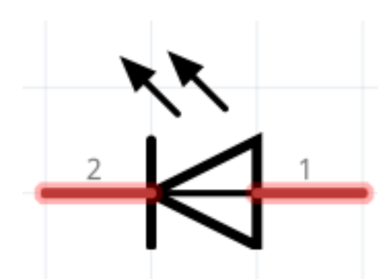
- Students will be able to
  - identify symbols for diodes, LEDs and switches
  - read a schematic, tracing current flow through a circuit
  - use a schematic to create a circuit on a breadboard
  - based on a circuit on a breadboard, recreate the schematic

Diodes & LEDs

- **Diodes** are like one-way valves: they allow current to only flow in one direction. They often have a line drawn around them to indicate the negative lead (cathode)

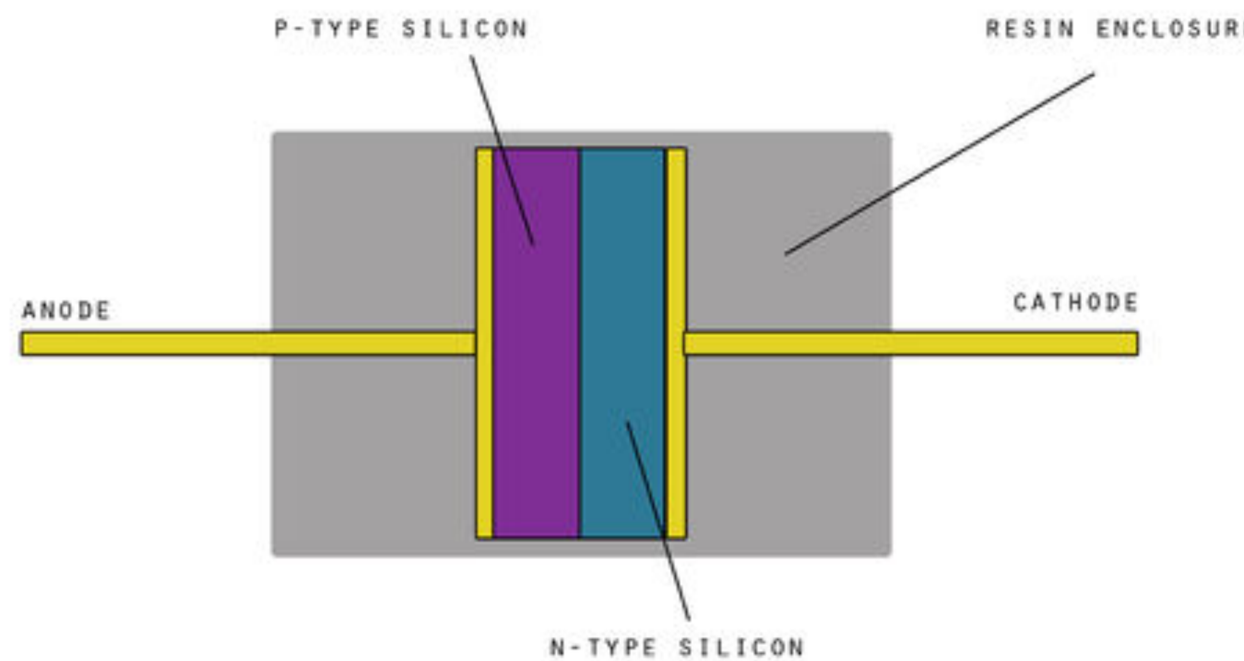


- **LEDs** are diodes that have the added benefit that they light up. The positive lead (anode) is usually the longer of the two. (Mnemonic: a + takes 2 lines, a - takes just 1, so + ought to be longer)

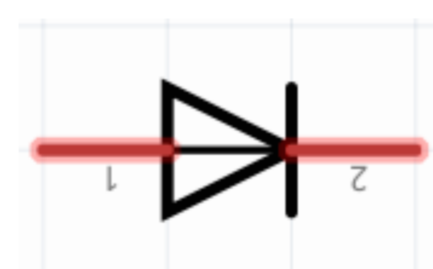


Diodes

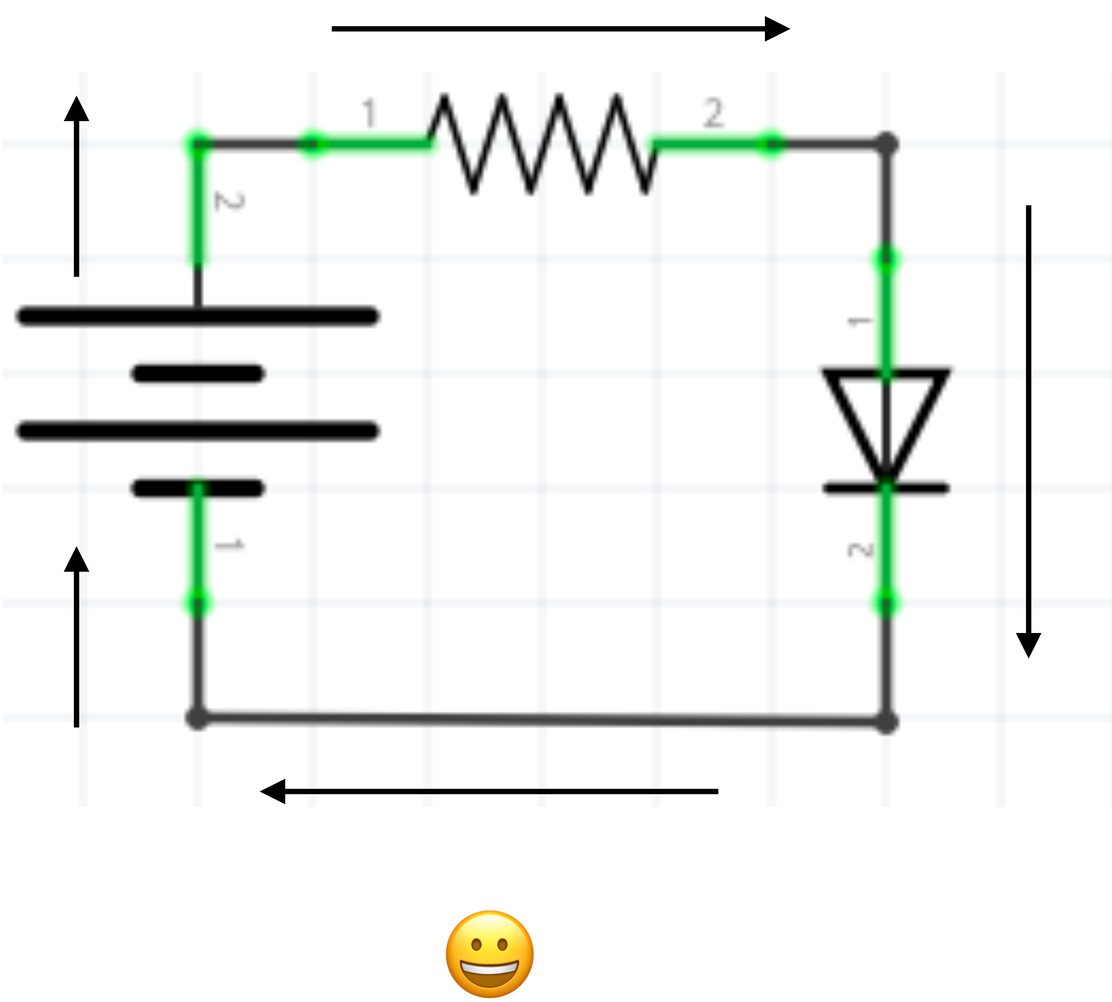
- Diodes are made two types of silicon.
  - n-type has **extra** electrons (negative)
  - p-type has **fewer** electrons (positive)
- The two types are sandwiched together
- Since the n-type has more electrons, electrons can easily flow *from* n-type to p-type (but not vice-versa),
- Thus current can flow in one direction easily, if a voltage of at least **V_F** volts is applied
- We call V_F the **forward voltage**, because it allows current to flow forward
- Current cannot flow in the opposite direction unless you apply a *lot* of voltage, known as the breakdown voltage

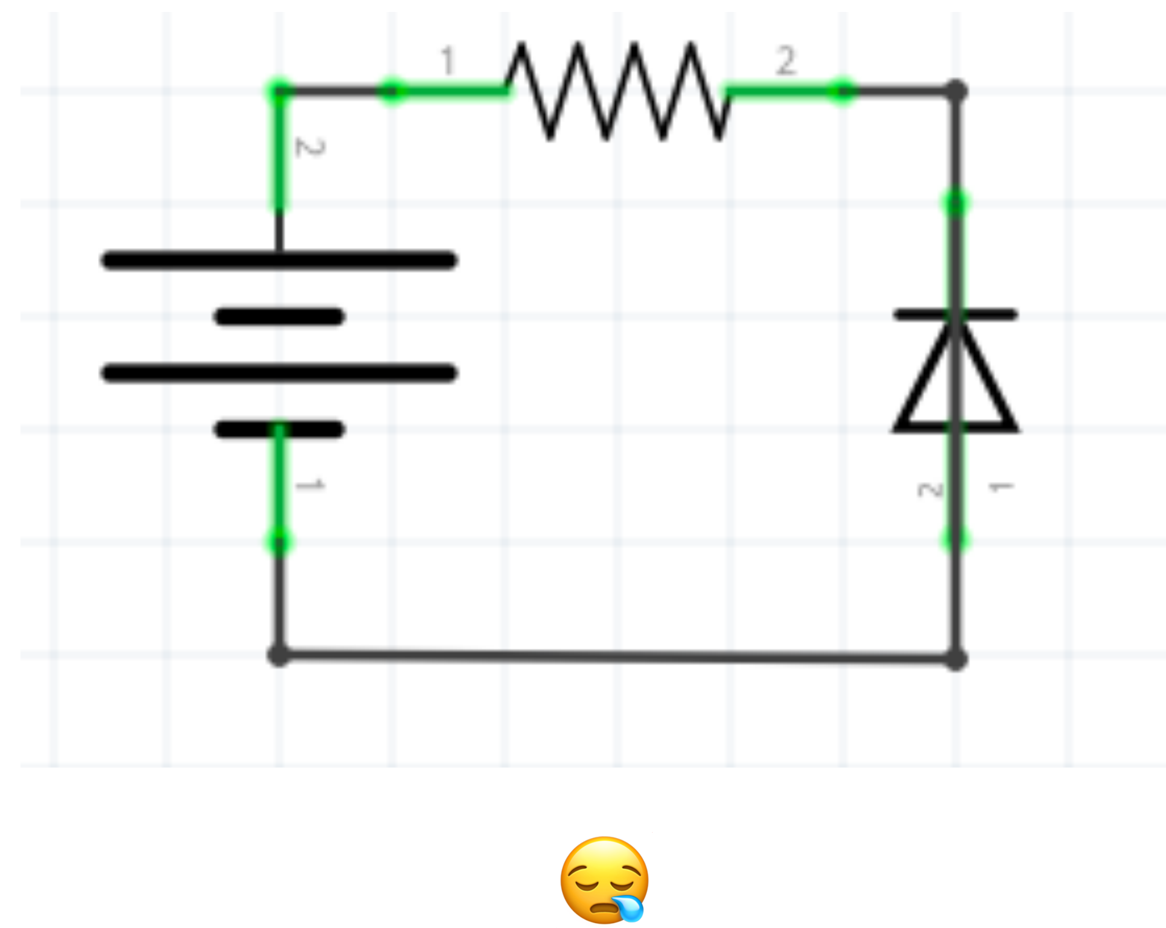


IF A VOLTAGE IS APPLIED ACROSS THE JUNCTION HOWEVER, SO THAT THE P-TYPE ANODE IS MADE POSITIVE AND THE N-TYPE CATHODE NEGATIVE, THE POSITIVE HOLES ARE ATTRACTED ACROSS THE DEPLETION LAYER TOWARDS THE NEGATIVE CATHODE, ALSO THE NEGATIVE ELECTRONS ARE ATTRACTED TOWARDS THE POSITIVE ANODE AND CURRENT FLOWS.

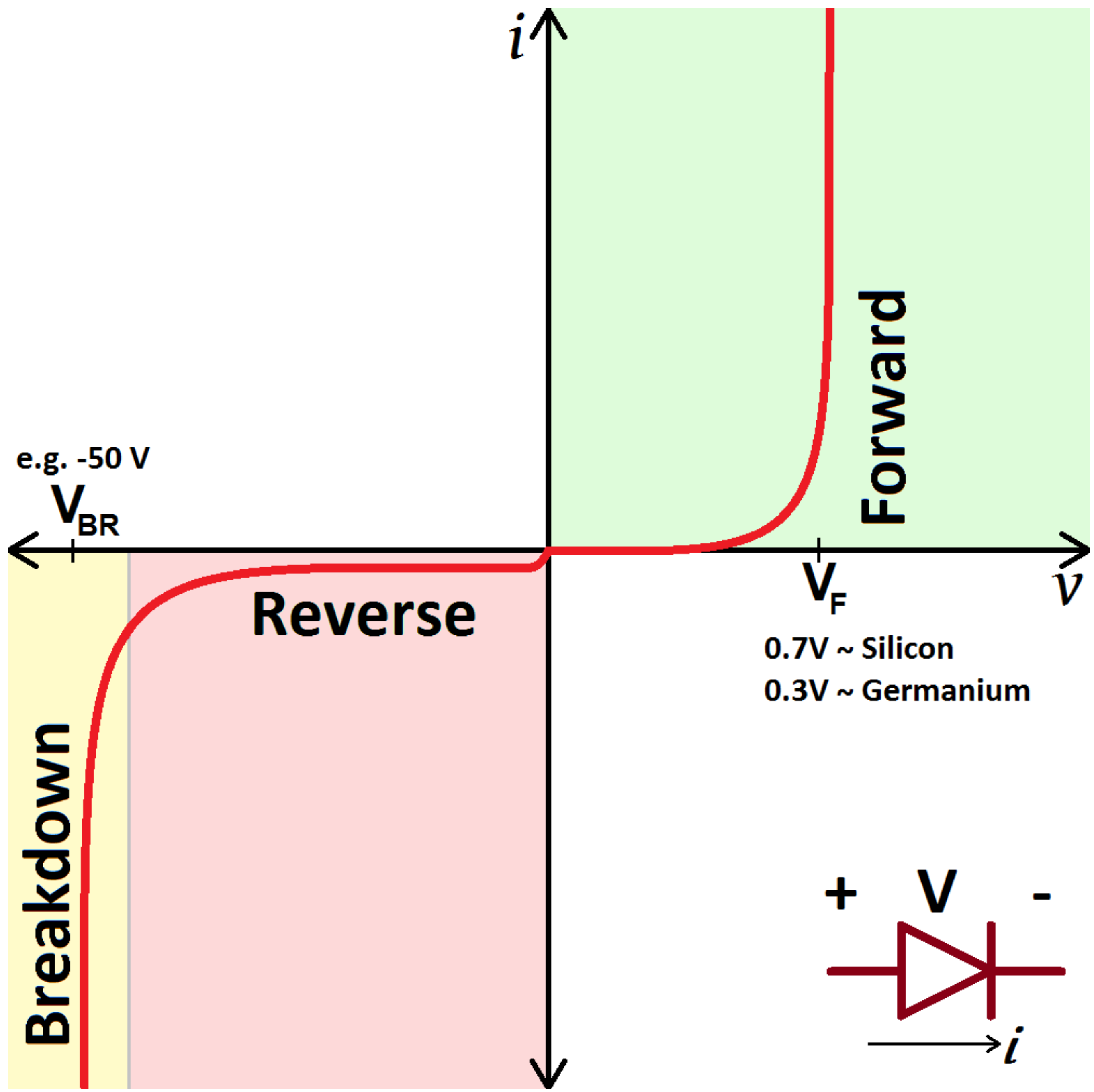


Diodes in Action & Inaction





Current v. Voltage



Click on the image to get to the source (sparkfun.com)

LEDs

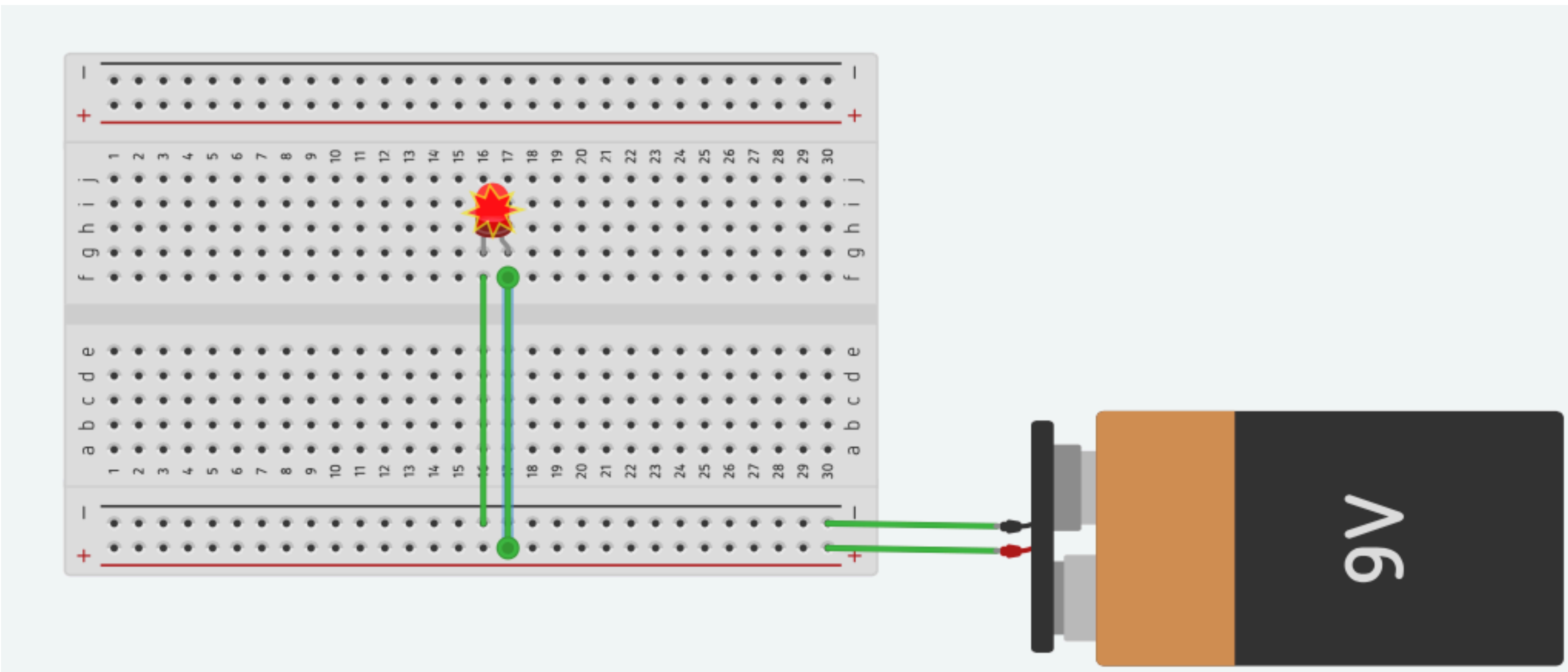
- LEDs — **L**ight **E**mitting **D**iodes — are, to state the obvious - **diodes:** they only work in one direction, and only* when $V \geq V_F$

- What distinguishes them from ordinary diodes is that **they glow** as the electrons jump across the barrier (the "junction") between the n and p silicon types

- They are *ubiquitous* in modern lighting systems, from cars to planes to street lights: if it blinks, it's likely an led

*technically speaking, if you apply enough of a breakdown voltage, that also might cause the LED to glow, but that would be because it's on fire. We will *not* test this in this course.

Resistance Isn't Futile ... It's *Required*!



- Without a resistor, too much current flows through the LED and it will fry (if not immediately, then eventually)

Techy Aside: The Diode Menagerie

- LEDs glow when electrons cross the NP junction
- Photodiodes are the opposite of LEDs: they allow current to flow only when light strikes them
- There are other types of diodes, which would be covered in an EE course (but not here)

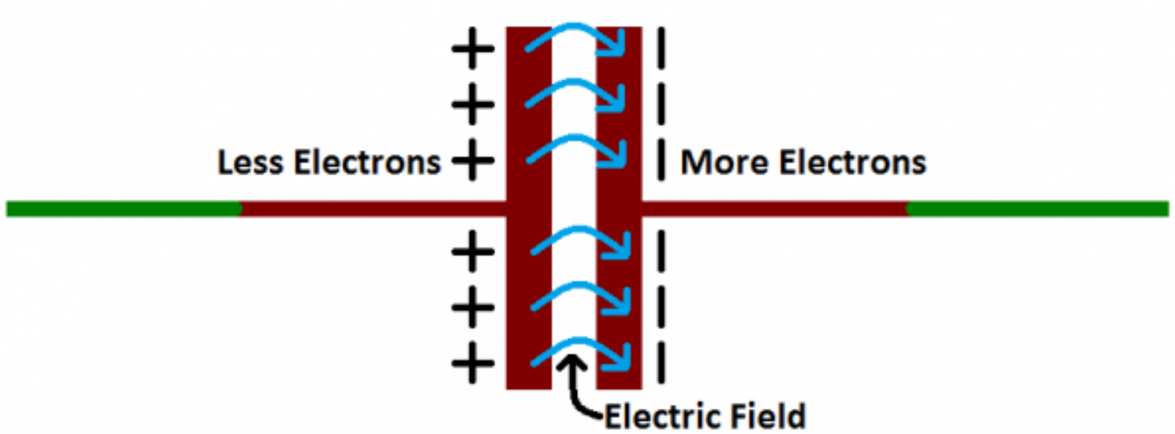
Capacitors

- Capacitors are **components that can store energy** (like a battery). They have two metal plates with an insulating **dielectric** in between. When charged, positive and negative charges gather on those plates and stay there — because of their mutual attraction.

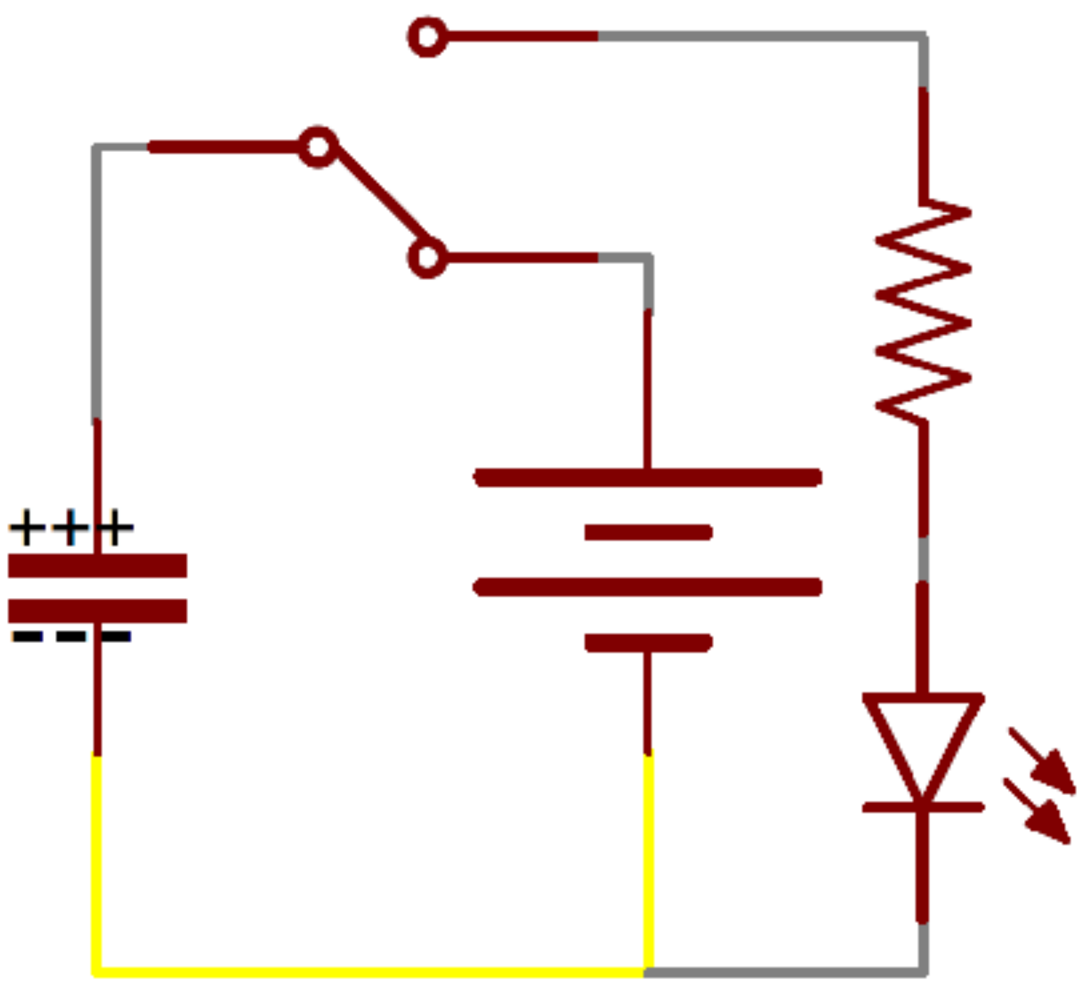
- A capacitor can only store a certain amount of charge. Its capacitance is measured in **farads**, although because a farad is huge, units are usually in microfarads (10^{-6}), nanofarads(10^{-9}) and picofarads (10^{-12})

- Capacitors are used for **energy storage**, **voltage spike suppression**, and **signal filtering**

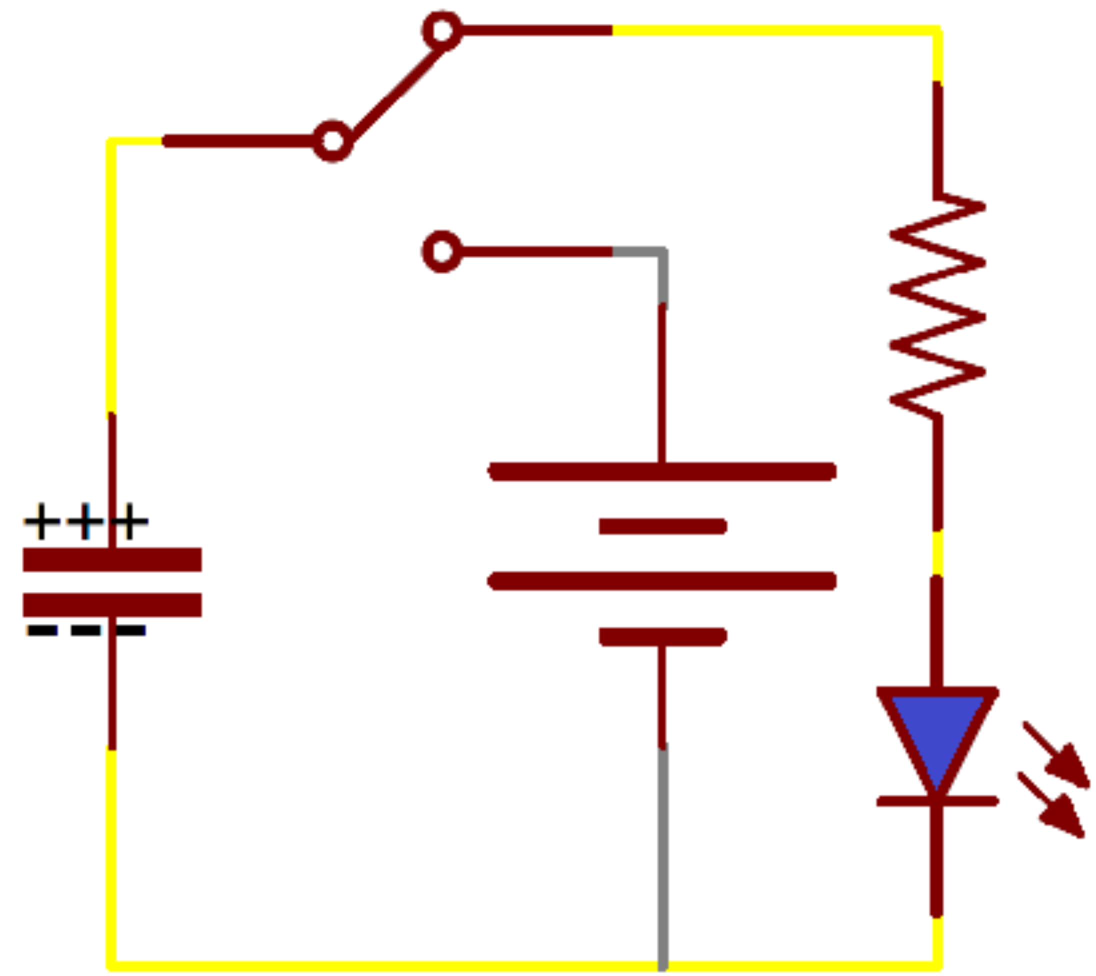
- We mention them here so that:
  - if you see them in a schematic you'll know what you are looking at
  - you'll appreciate that **an unplugged electrical/electronic device can still kill**
  - when supercapacitors replace batteries, you won't be surprised



Capacitors @ Work



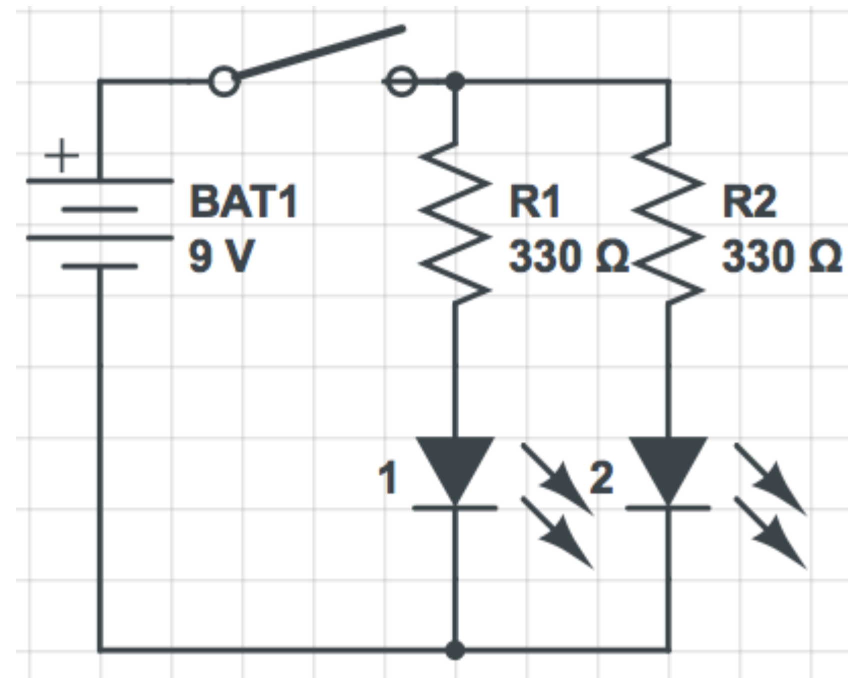
Charging



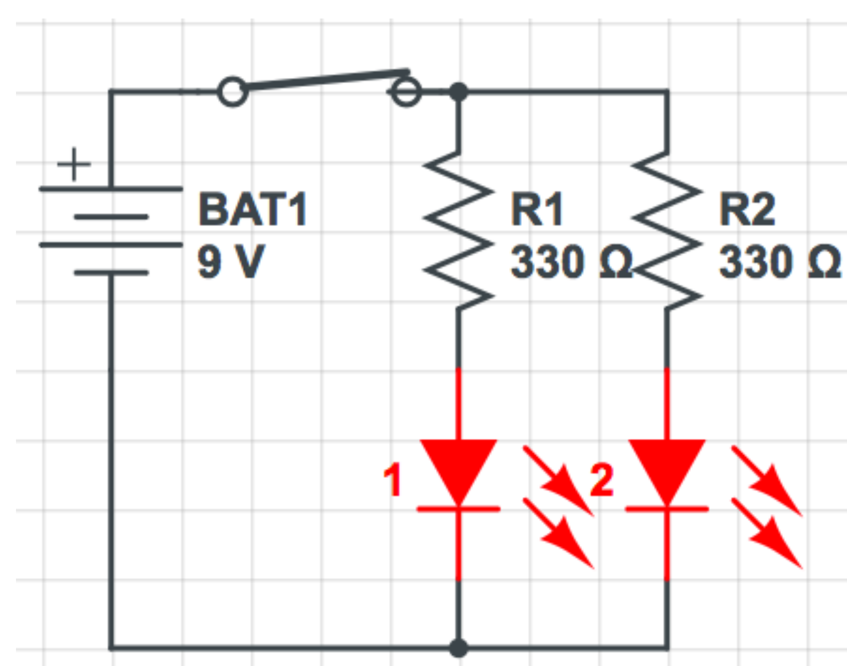
Discharging, powering the LED

Switches

- A closed circuit is one in which there is a continuous loop from anode to cathode. An open circuit is one in which there is a gap of some sort.
- A **switch** can be used to control whether or not a circuit is closed.
- A switch is **closed** when it can conduct electricity, **open** when it cannot
- Switches like those shown below are **maintained** switches, because they maintain their setting until changed.



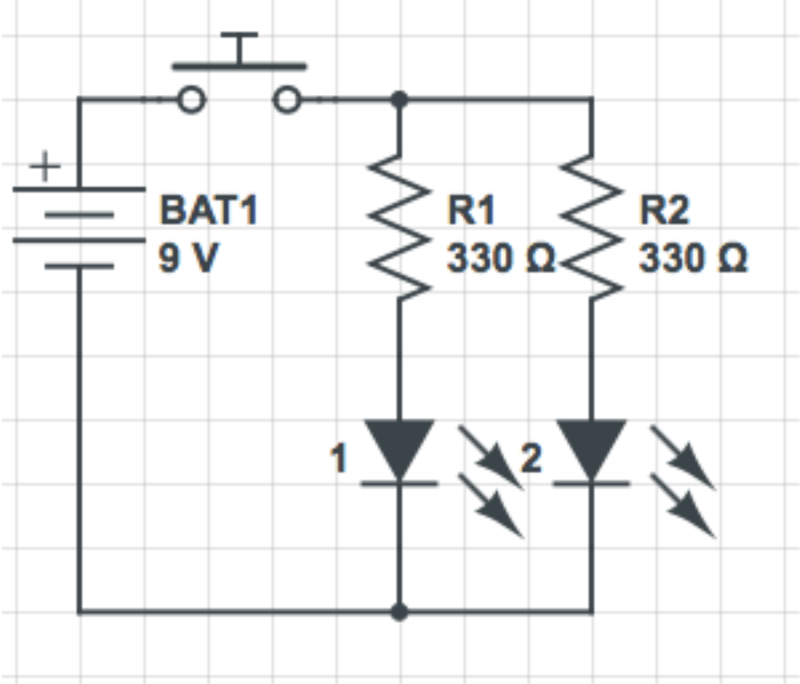
An open switch: no current flows

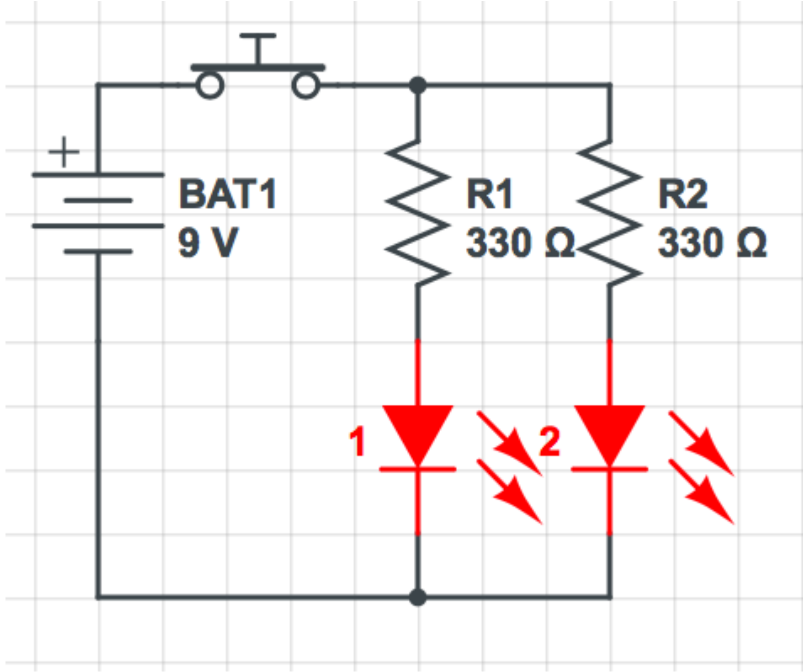


A closed switch: the LEDs are lit

Switches

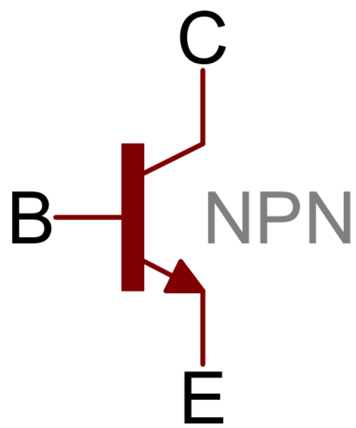
- The switch below is **momentary** (like a doorbell), staying in one state only when pressed, and then reverting to a default state.
- It is a push button switch, or **button** for short
- Most push buttons are normally open
- We will use the term "switch" and "button" interchangeably, as the switch in your kit is a button

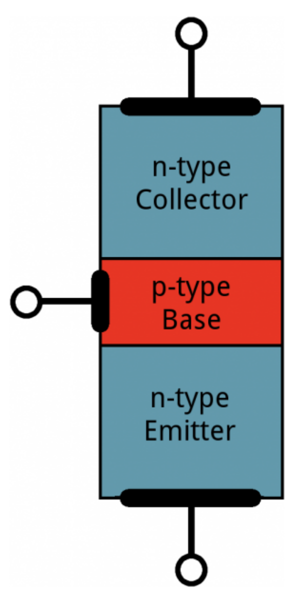




Aside: Transistors

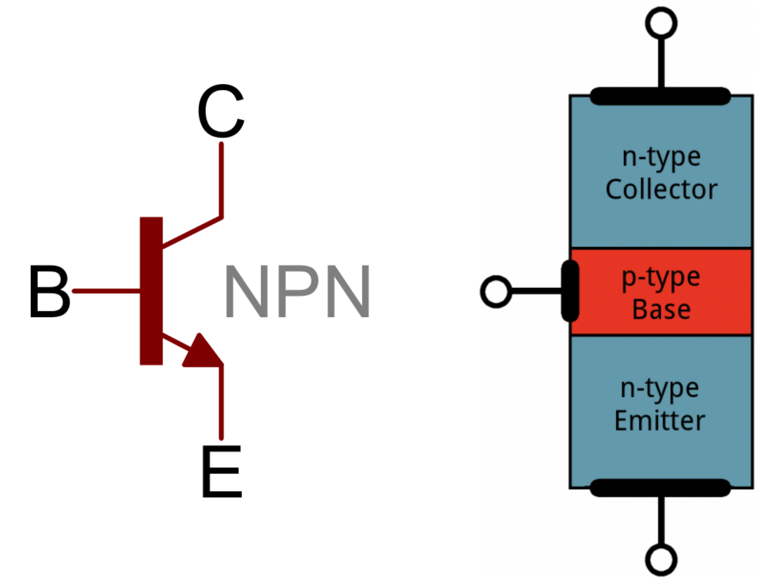
- A transistor can be used as
  - an electronically controllable switch, or
  - to amplify a signal.
- It consists of the same semiconductors , n-type and p-type, used to construct diodes
- The regions of the transistor are the **collector**, **base**, and **emitter**

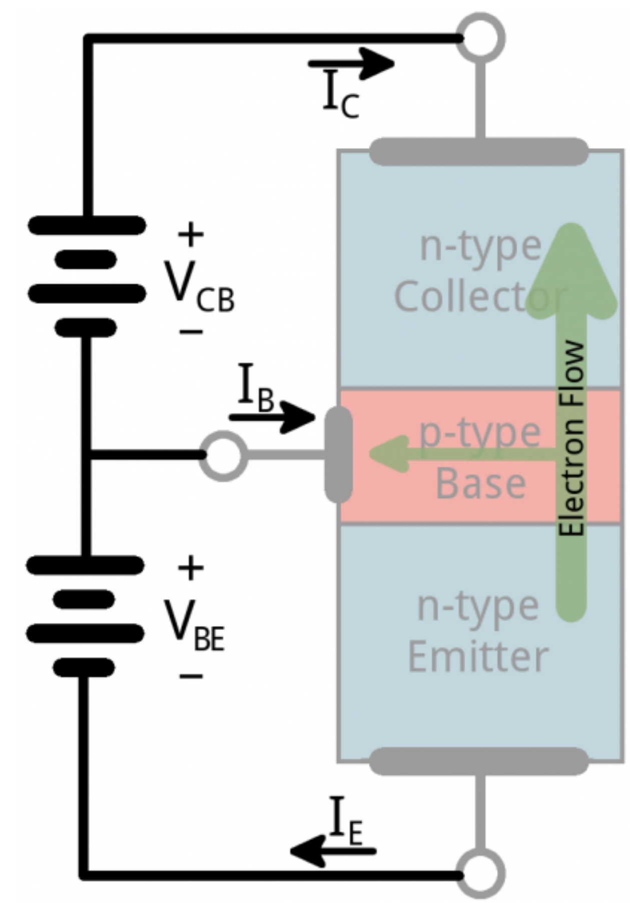




Aside: Transistors

- Electrons can flow easily from n-to-p regions, with just a little voltage
- Normally, to flow from the p-type base to the n-type collector requires a lot of voltage, unless a sufficient voltage is applied to the base.
- Depending on the amount of voltage at the base, the transistor can either
    - allow current to flow unhindered from the C to E, or allow no current to flow (switch)
    - modulate the amount of current from C to E based on the amount of current flowing into B (amplifier)



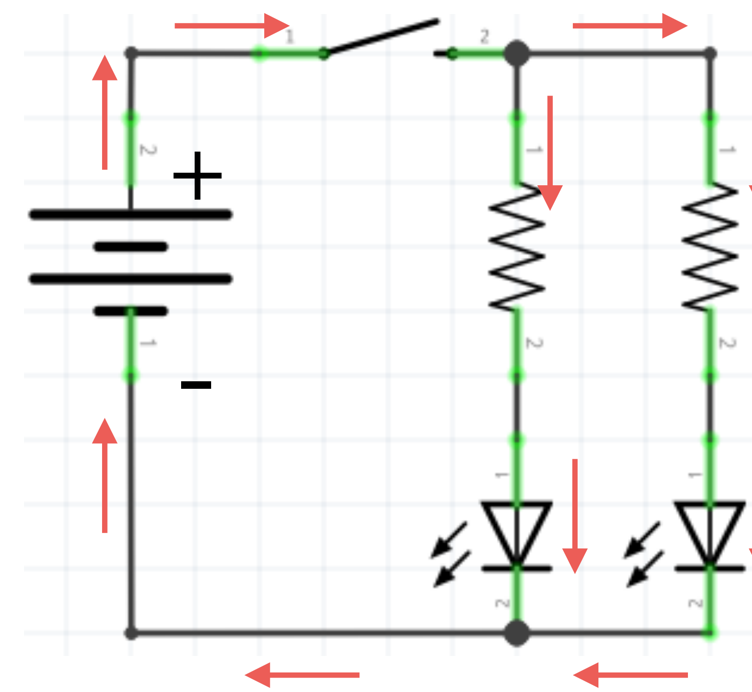


Conventional Current v. Electron Flow

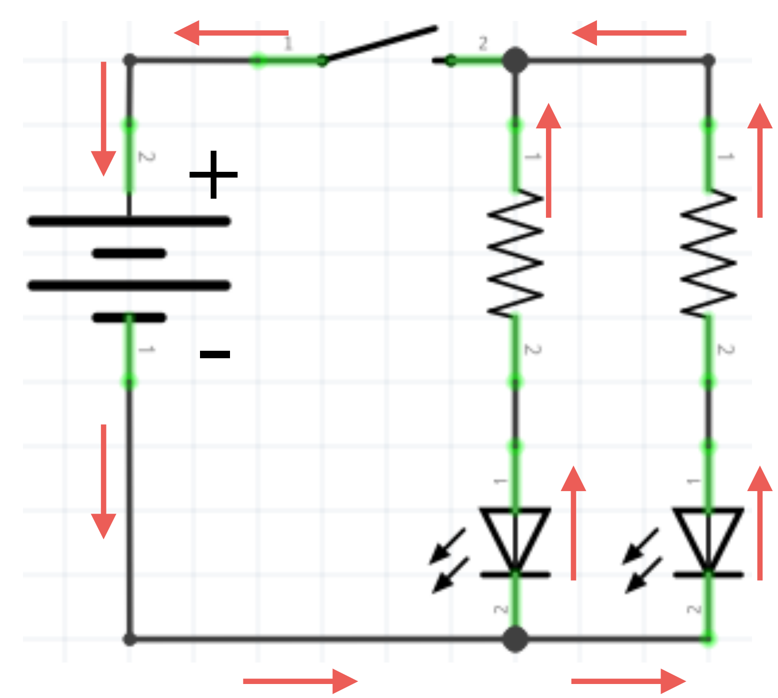
- Due to a slight misunderstanding at the dawn of the electrical age, it was thought that positive charges emerged from the anode (+) and ended up at the cathode (-). This is called **conventional current** flow.

- Electricity involves the flow of electrons, which emerge from the cathode (-) and end up at the anode (+). This true state of affairs is called **electron flow**.

- <u>Rumor has it</u> that there are electronics textbooks that are published in CCF and EF versions, and that community colleges and vocational schools tend to use EF, whereas university curricula tend to use CCF. In this course, we will use *conventional current flow*.



CCF



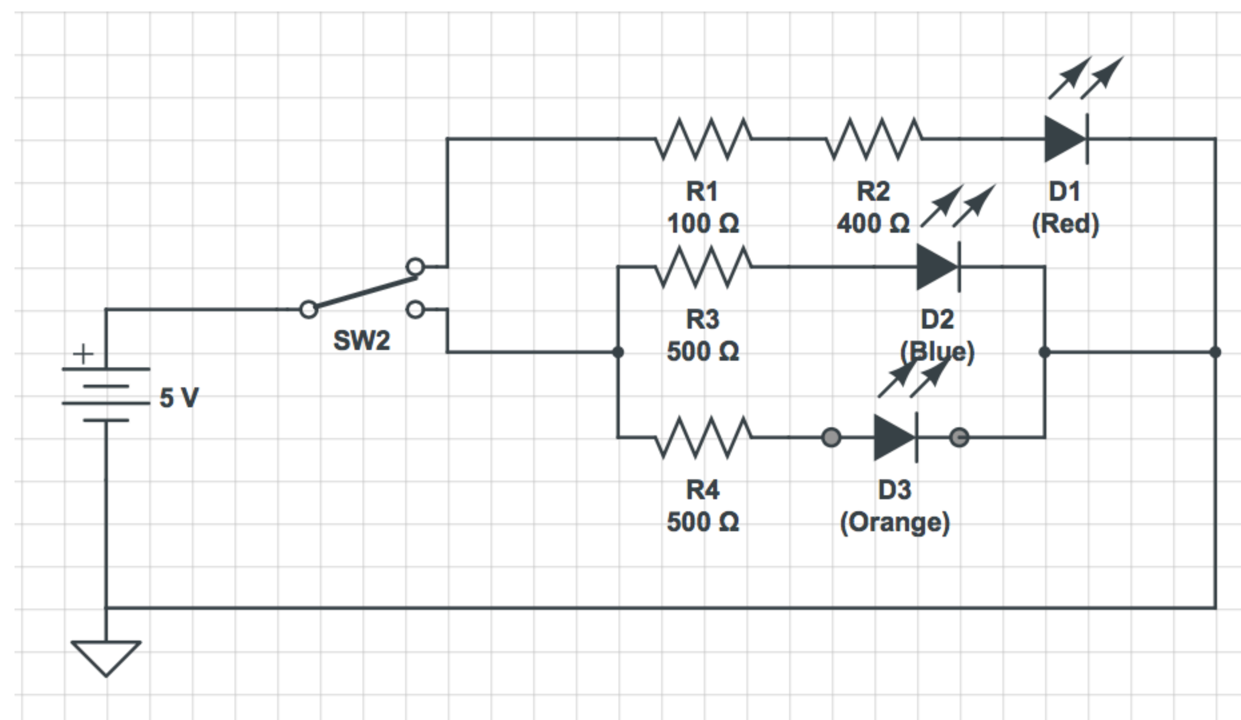
EF

Conventional Current Flow v. Electron Flow: The Origin Story

WE WERE GOING TO USE THE TIME MACHINE TO PREVENT THE ROBOT APOCALYPSE, BUT THE GUY WHO BUILT IT WAS AN ELECTRICAL ENGINEER.

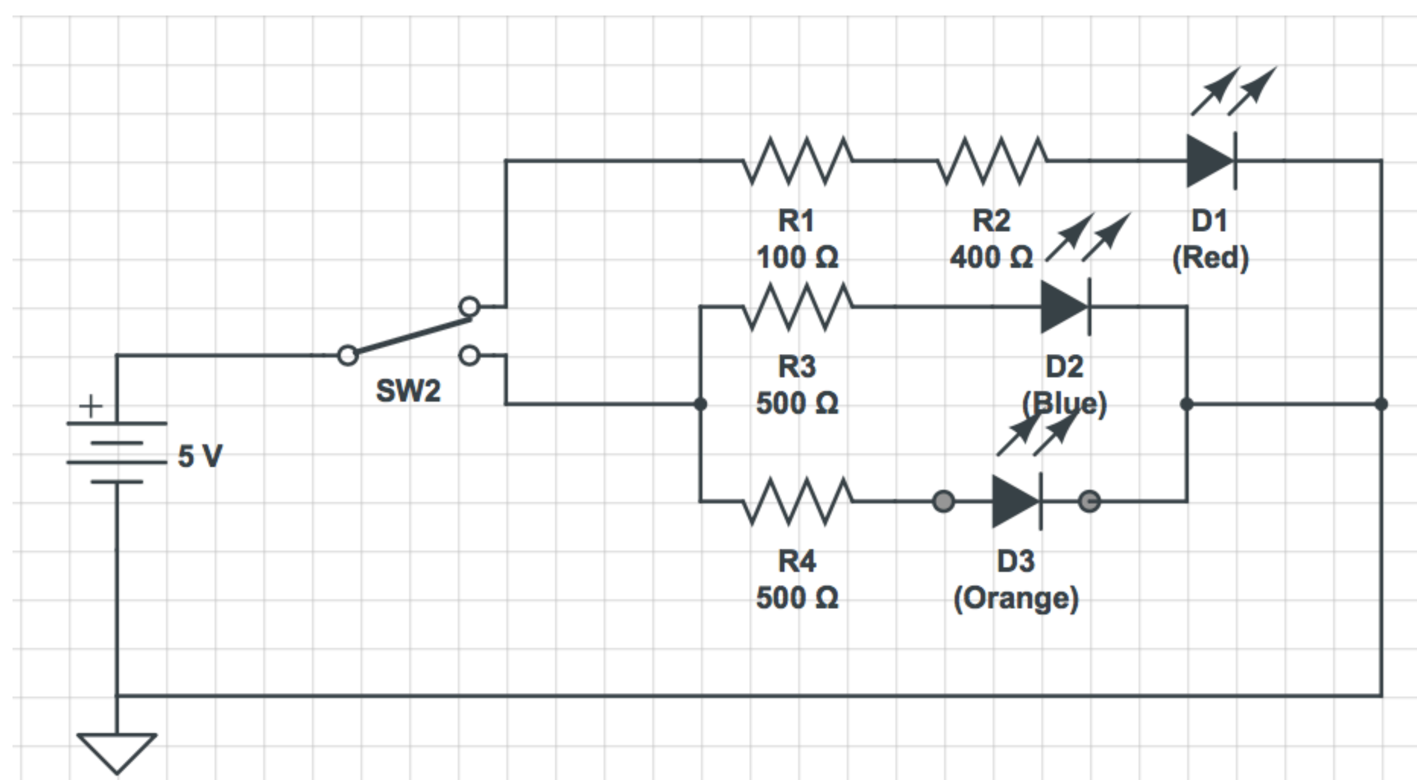
Reading Schematics

- As mentioned earlier, a schematic is a diagram that uses symbols to represent an electronic circuit. Proficient IoT'ers must be able to both read and write schematics.
- When examining a schematic, remember first and foremost that it is a loop: barring a breakage (e.g., an open switch), electricity will flow from the anode (+) to the cathode (-)
- By convention, the battery should be vertically oriented (+ on top, - on bottom), and generally put the battery on the left hand side of the circuit
- Each component will have a name (e.g., B1 for battery, R1 for resistor 1, etc.) that can be placed on a printed circuit board (PCB) to make construction easier



OOCE*: Schematics

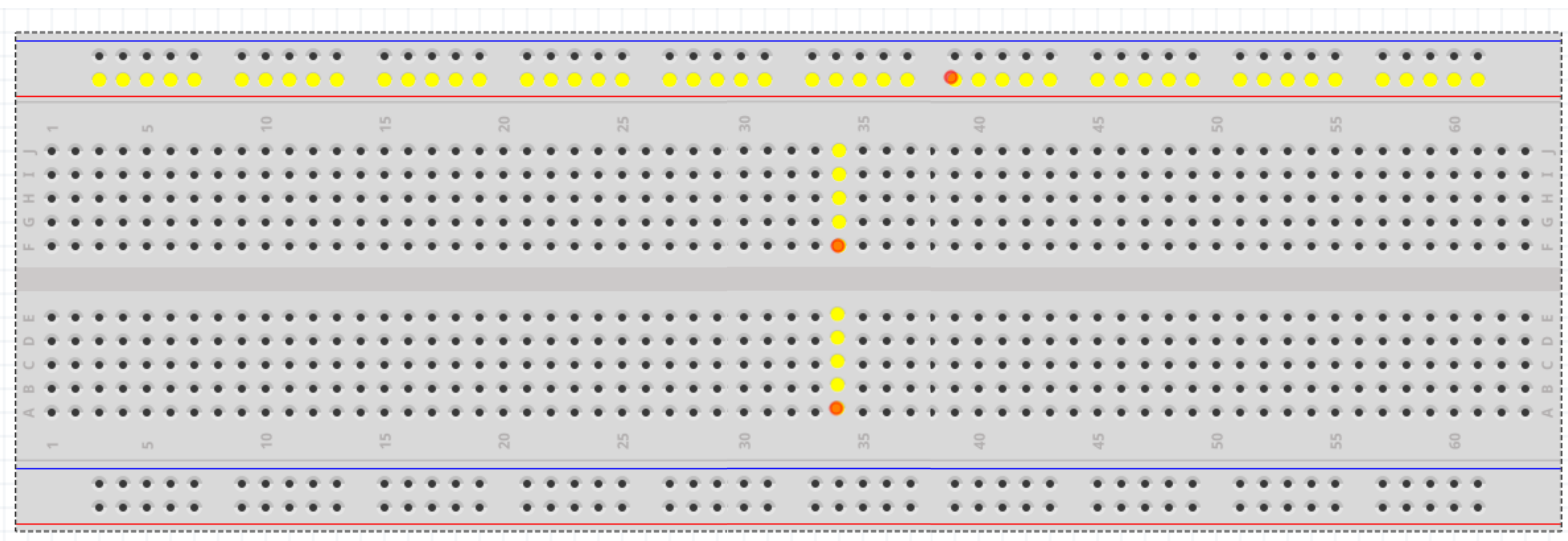
- When is the series arrangement of resistors relevant? The parallel arrangement?
- Find the circuit resistance when SW2 is up and down
- Find the current through R2 and R4
- Find the voltage drop across R1 and R2 (assume that D1 has a voltage drop of 1.8V, typical of a red led)



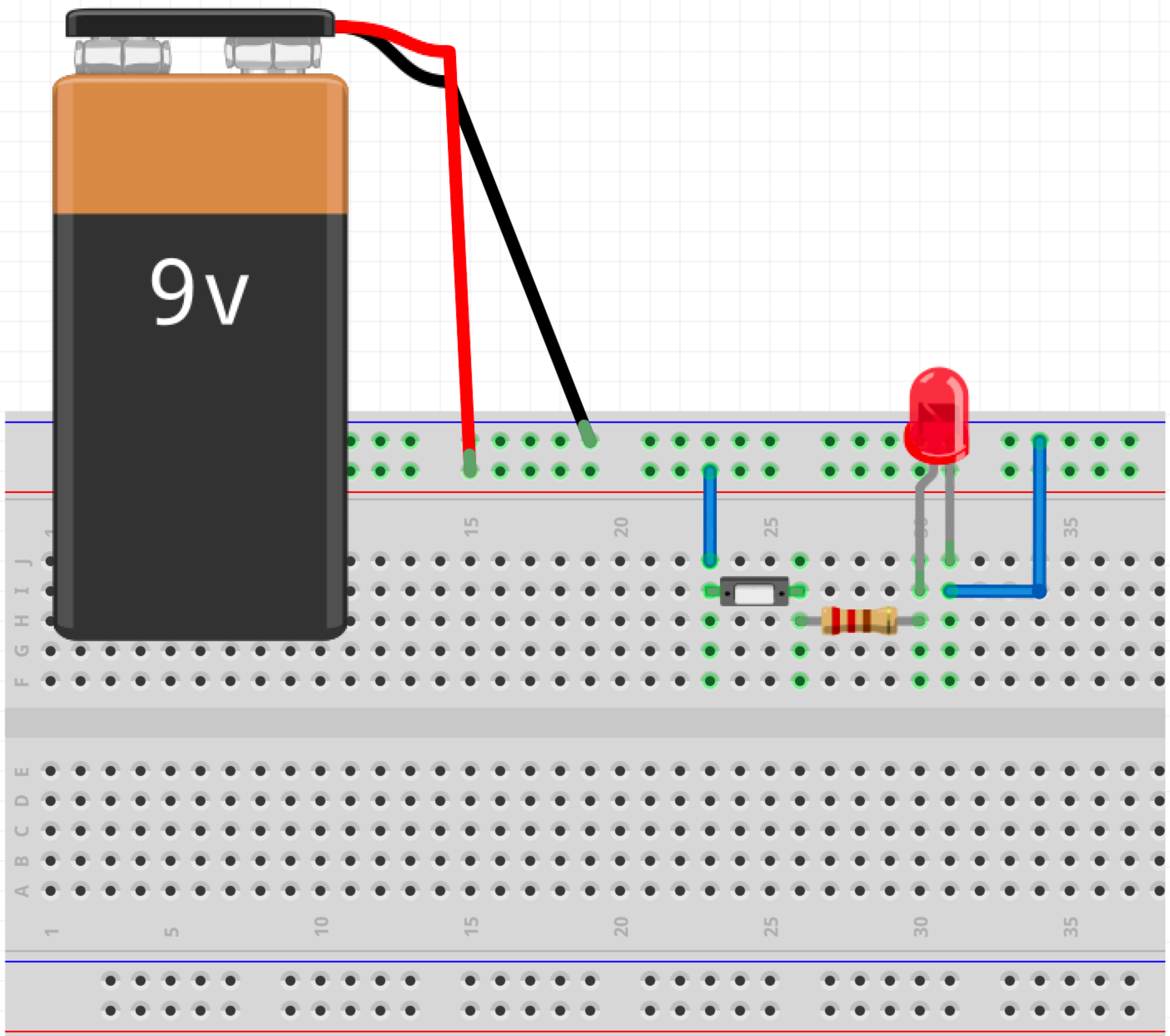
*out of class exercise (assigned at instructor discretion)

Breadboards

- A breadboard is a clever metal/plastic contraption that allows a IoTer to prototype a circuit easily.
- Component leads are inserted into the holes, and there is an electrical connection among each set of 5 vertical holes and along the 2 top and bottom rows



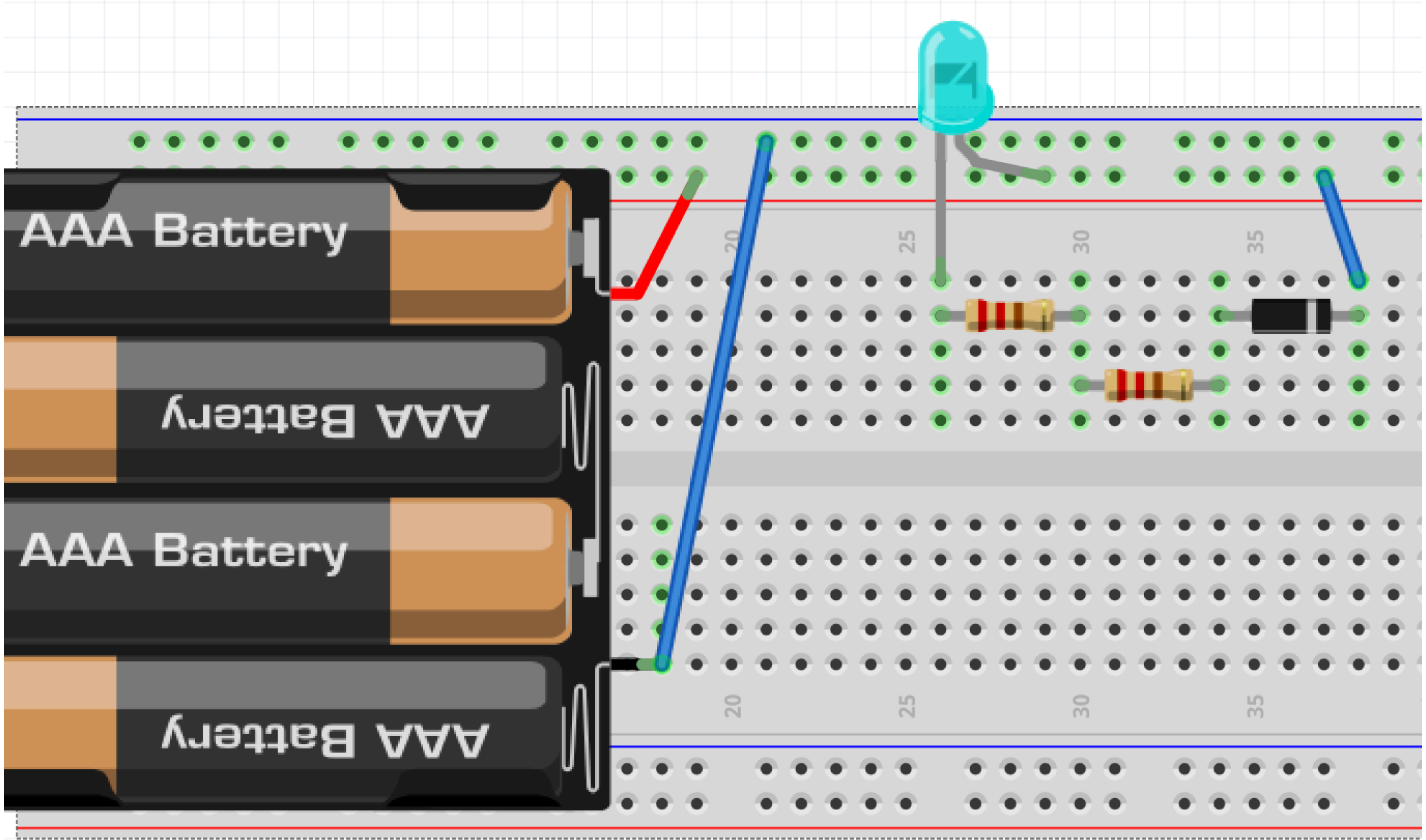
Breadboard v. Schematic



1. Draw the battery
2. Trace from the anode to ... the switch
3. Draw the switch
4. Trace from the switch to ... the resistor
5. Trace from the resistor to the LED
6. Trace from the LED to the cathode
7. Done!

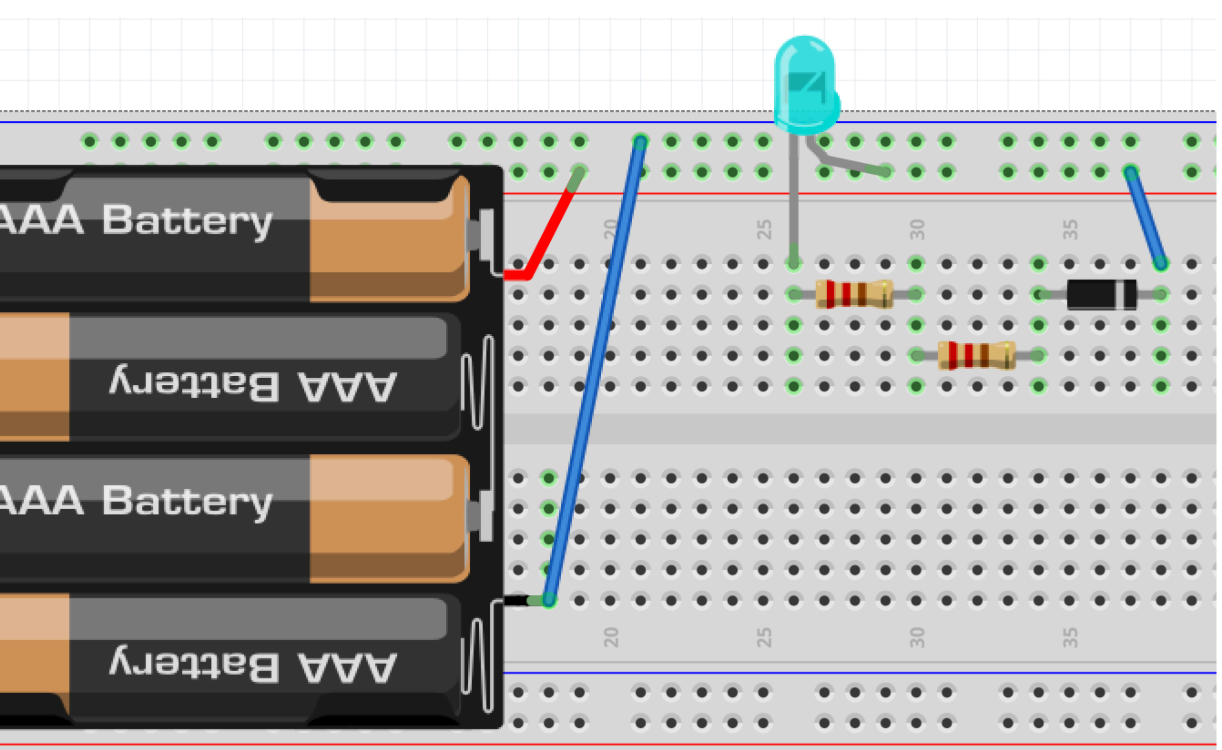
ICE: Breadboard to Schematic

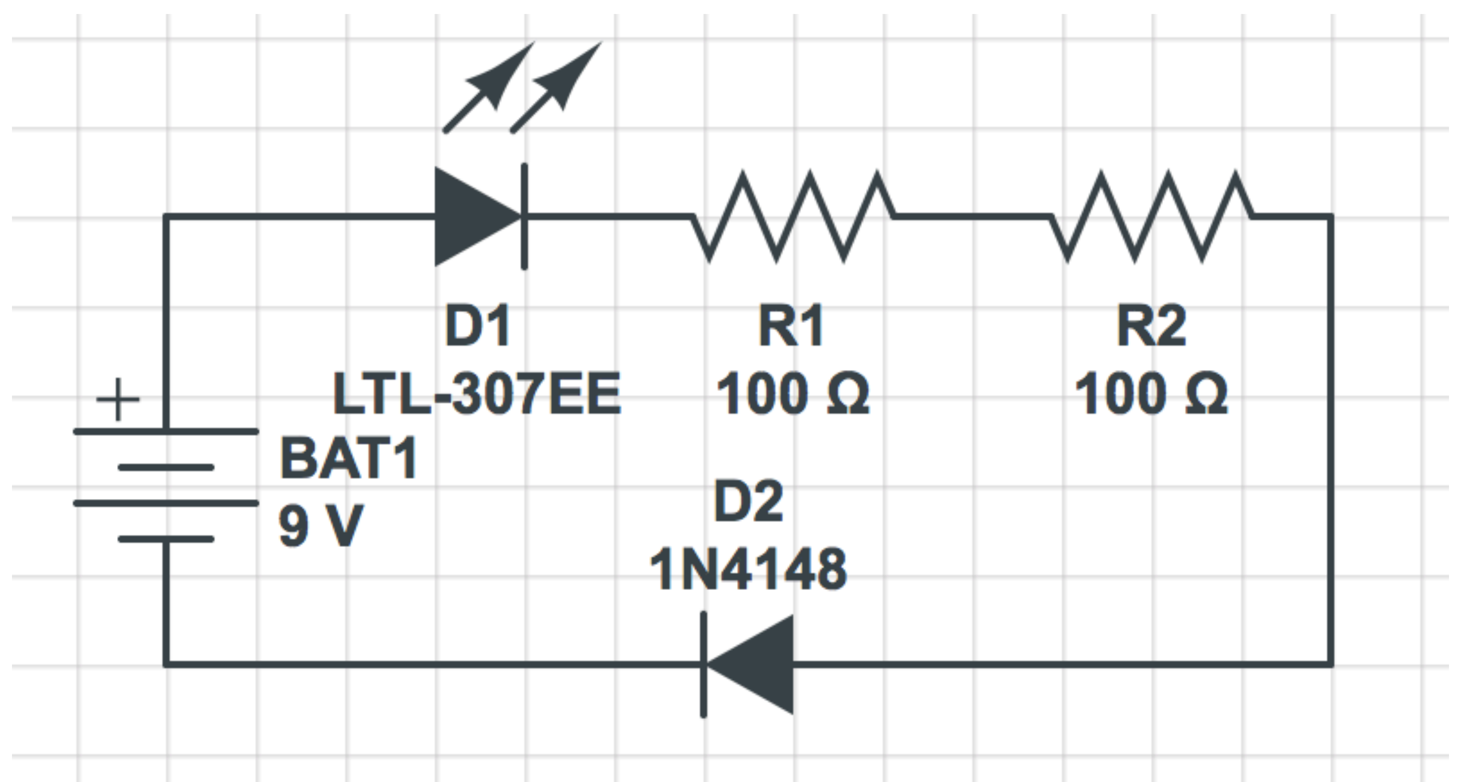
- Draw the schematic corresponding to the breadboard below



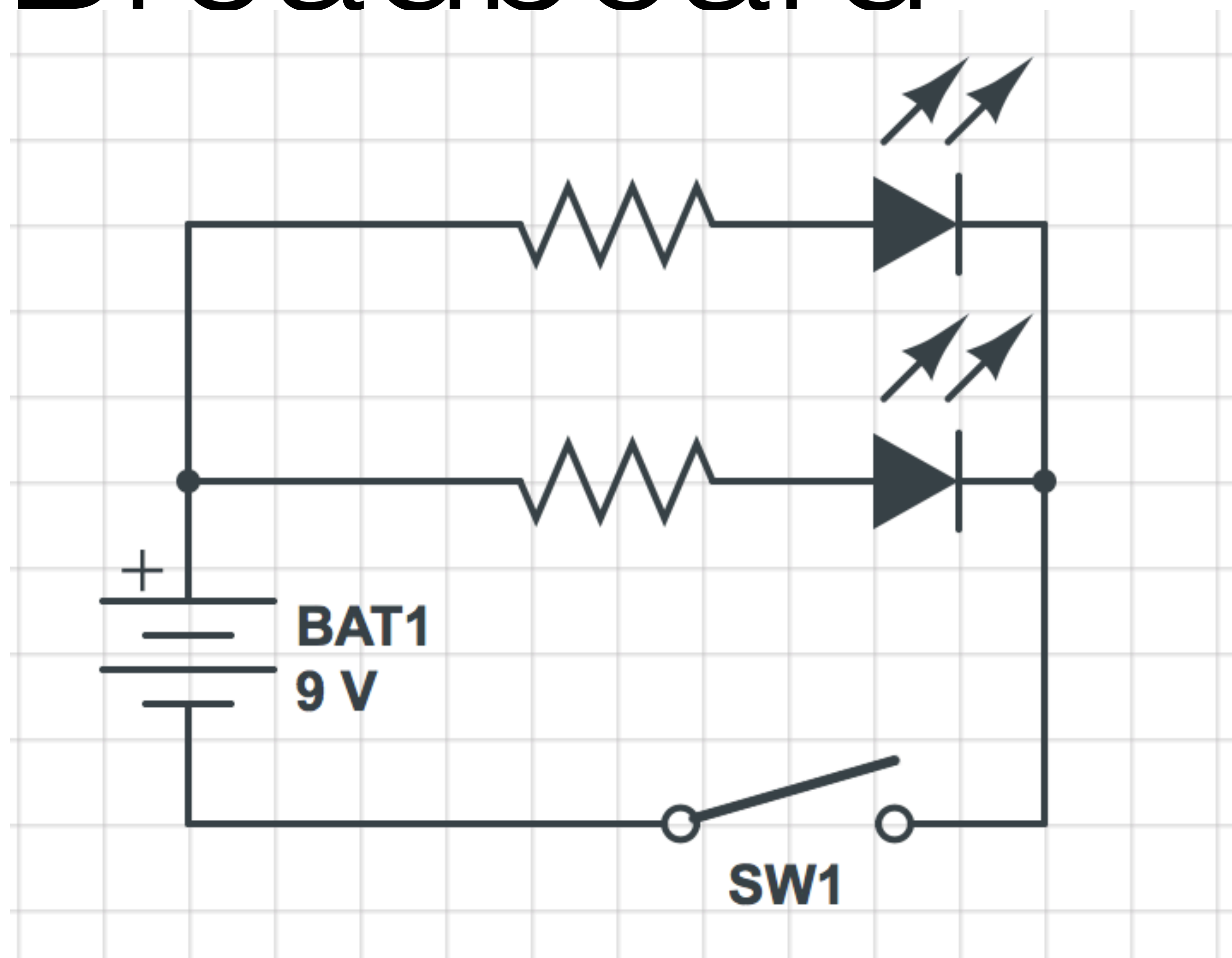
ICE: Breadboard to Schematic - Solution

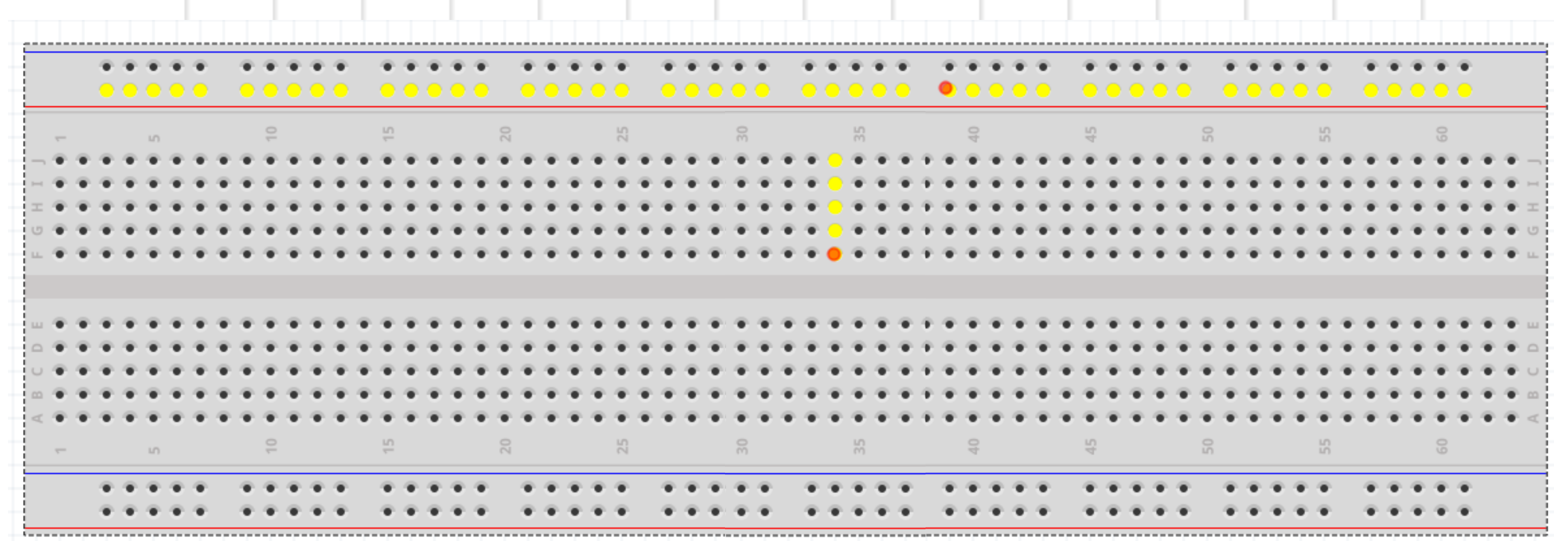
- Draw the schematic corresponding to the breadboard below



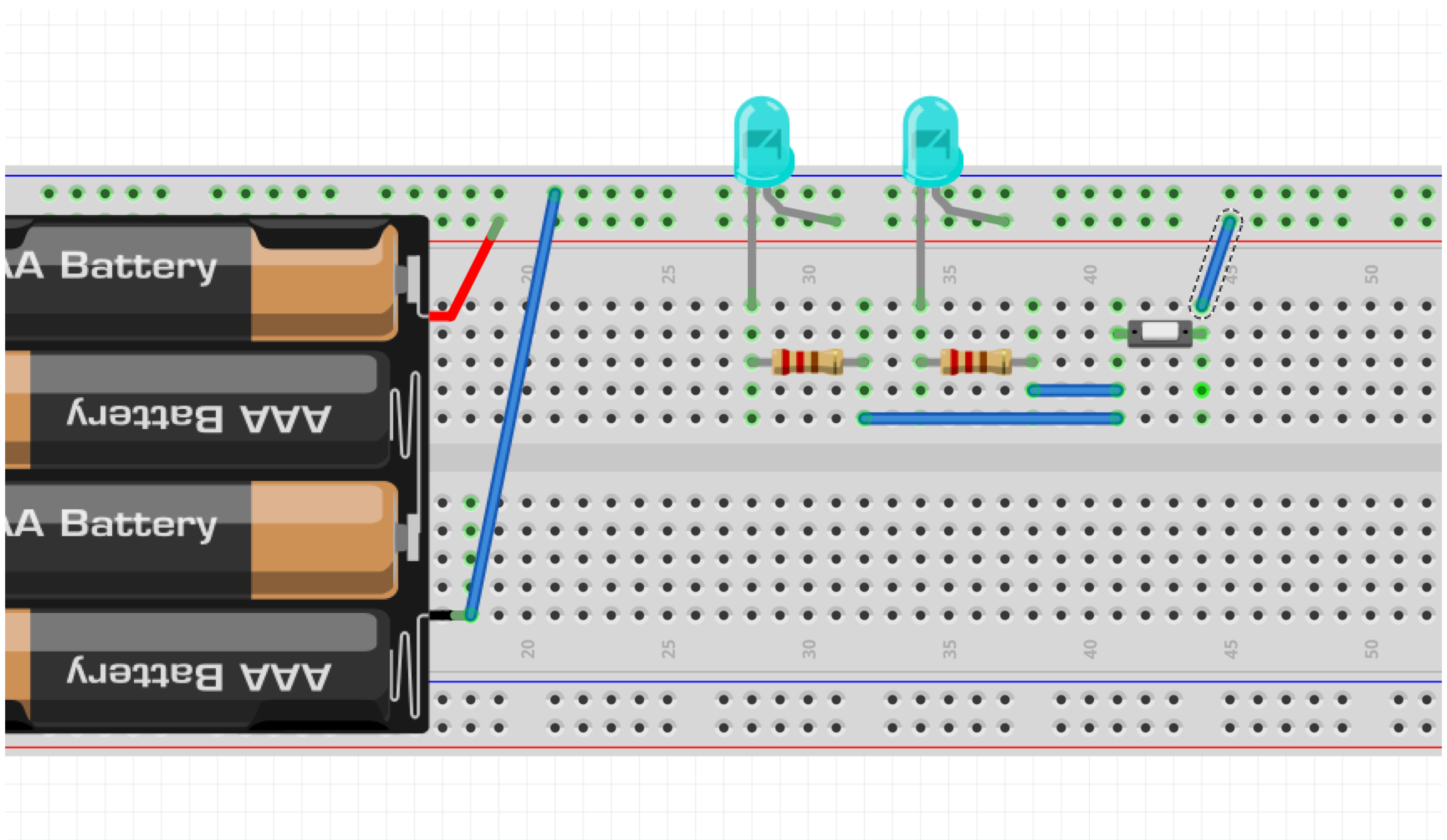


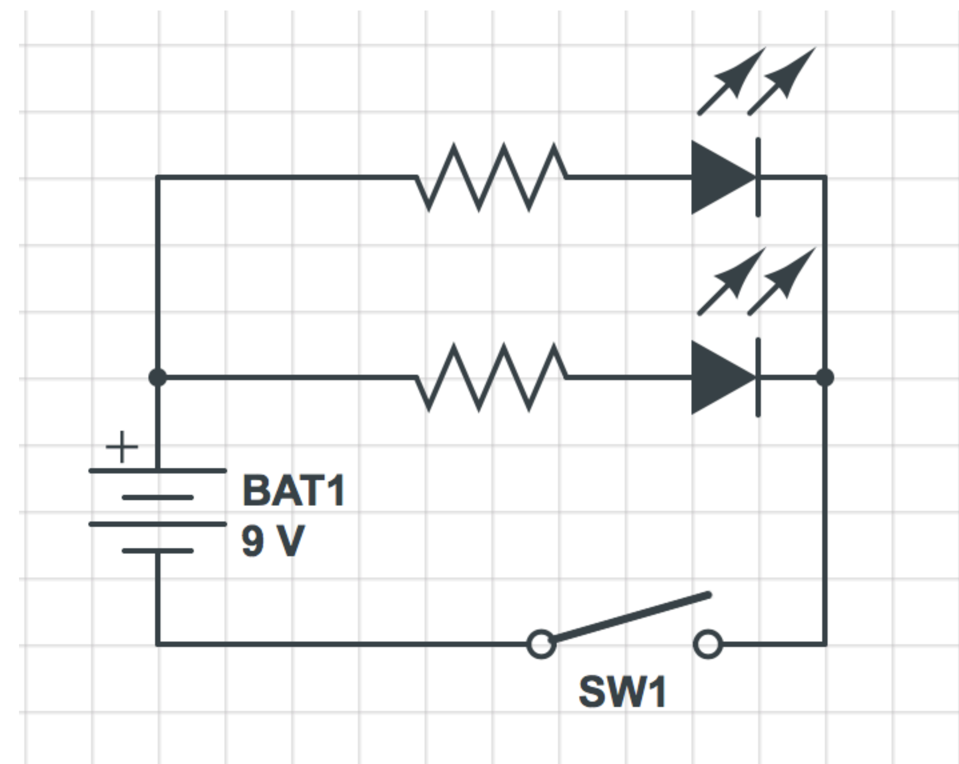
ICE: Schematic to Breadboard



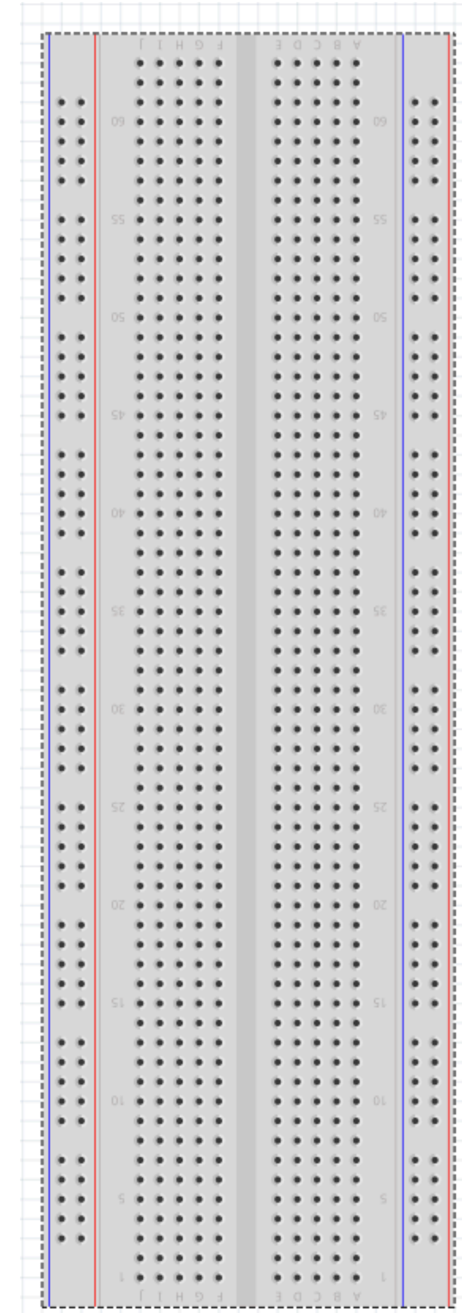


ICE: Schematic to Breadboard - Solution





Exercises



1. Draw a picture of the following components:

    - battery, resistor, capacitor, switch, wire, diode, LED

2. Which breadboard holes are electrically connected?

3. Which way does electricity really travel? Which way using conventional current flow? Electron flow?

4. A resistor has green, orange, black bands. What is its resistance?

5. What bands does a resistor with 3800Ω display?

Programming Exercise

1. Write a C++ program that prompts the user for the colors of 4 bands and prints out the resistance. Use the std::string class, so you can prompt the user using words rather than just characters (it would get tricky with blue, brown and black all starting with 'b'). And you might want to check out std::vector just to make life easier. [Ask if you get stuck].

Resources

- Bayle, Julien. *C Programming for Arduino*. Packt Publishing, 2013.
- https://learn.sparkfun.com/tutorials/what-is-electricity
- http://www.colorado.edu/physics/phys1120/phys1120_fa09/LectureNotes/Voltage.pdf
- Monk, Simon. *Hacking Electronics:An Illustrated DIY Guide for Makers and Hobbyists*. McGraw-Hill, 2013.
- https://www.ampbooks.com/mobile/tutorials/lesson-002/
- https://www.eeweb.com/toolbox/4-band-resistor-calculator/
- http://www.mi.mun.ca/users/cchaulk/eltk1100/ivse/ivse.htm#
- http://www.nutsvolts.com/magazine/article/which-way-does-current-really-flow
- https://learn.sparkfun.com/tutorials/capacitors
- http://www.electronics-tutorials.ws -- nice set of tutorials
- http://www.electronics-tutorials.ws/resistor/res_3.html
- http://www.instructables.com/id/How-To-Diodes/