Basic Circuits

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Basic Electricity

- Electricity is energy moving through the medium of electrons
- Analogies
  - Ocean Wave moving
  - Hydraulic Analogy

Electricity	Units	Abbrev	Hydraulic Analogy
Circuit			Water in a closed loop of pipe
Voltage	Volt	V	Water pressure
Current	Amps	A	flow
Power	Watt	W	Energy/time
Resistance	Ohms	Ω	Resistance to flow (friction)

Hydraulic Analogy

https://en.wikipedia.org/wiki/Hydraulic_analogy

Electrical Component	**Hydraulic Equivalent**
Battery	Pump
Resistor	Friction in Pipe
Wire	Pipe

SI Units

- Volt (V) Energy/electron
- Current (Amps, A) number of electrons/second
- Resistance (Ohms, Ω, R)
- Power (Watts, W)
- Energy (Joules, J)

SI Prefixes

Name	Abbreviation	Value
Pico	p	10^{-12}
Nano	n	10^{-9}
Micro	μ	10^{-6}
Milli	m	10^{-3}
Kilo	k	10^{3}
Mega	M	10^{6}
Giga	G	10^{9}

Units with Prefixes

- $10^{3} ohms = 1 kilo - ohm$
- $10^{6} Watts = 1 Megawatt (MW)$
- $10^{9} Volts = 1 Gigavolt (GV)$
- $10^{-3} Amps = 1 milliAmp (mA)$
- $10^{-6} meters = 1 \mu m = 1 micron$
- $10^{-9} seconds = 1 nanosecond = 1 ns$
- $10^{-12} seconds = 1 picosecond = 1 ps$

Basic DC Circuit Variables

- Voltage: Analogous to water pressure
  - The force that moves electrons around the circuit
  - Energy per electron
- current
  - The number of electrons flowing per unit time
- Resistance
  - The resistance to the flow of electricity
  - Analogous to friction
  - Converts some current to waste heat

Ohm's Law: $V = I \cdot R$

Analog Circuits

- Analog means a point in the circuit can have any voltage
- It takes time to change voltage because of capacitance

Digital Circuits

- Digital is a simplified abstraction of Circuits
- Fixed voltage levels (can be multiple levels)
- For this course we consider only 2 levels
- High (V_{cc}) and low ($0V$)
- High (1) and Low (0)
- Any extraneous signal (noise) can be ignored
- Theoretically instantaneous

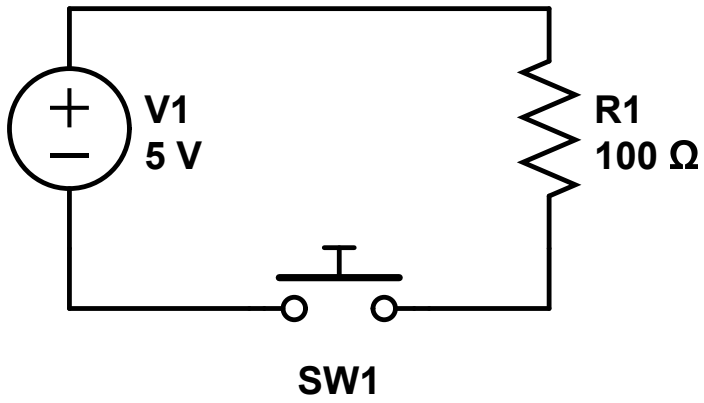
Practical Digital Circuits

- Digital is a simplified abstraction of Circuits
- We consider only high (V_{cc}) or low ($0V$)
- High (1) and Low (0)
- Any extraneous signal (noise) can be ignored
- Theoretically instantaneous

Correct Terminology: Forget "on" and "off"

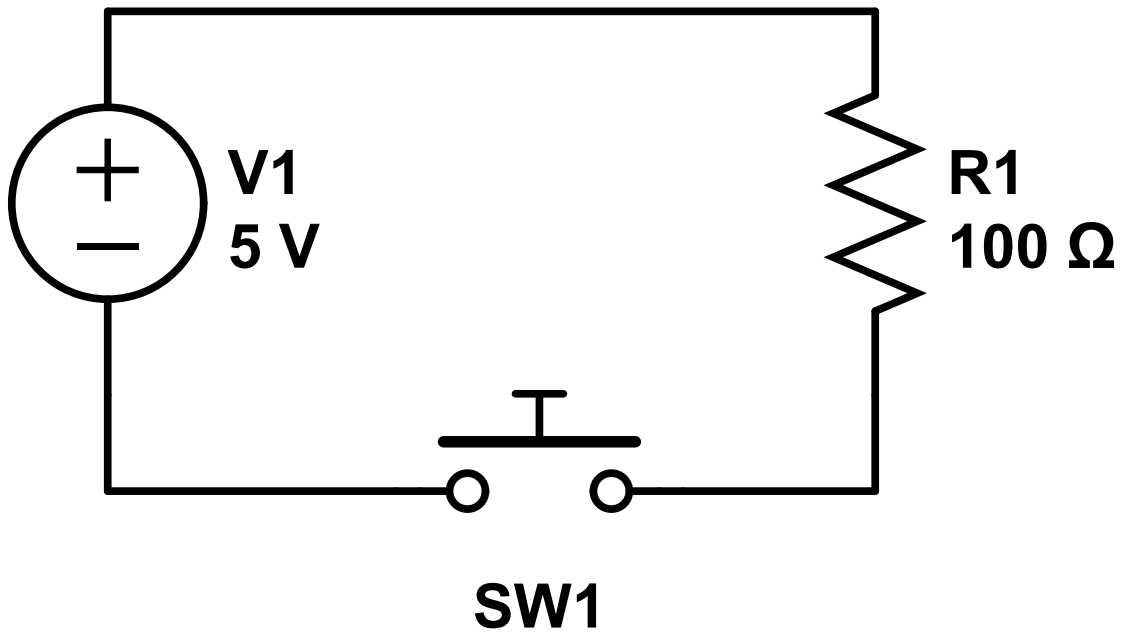
Turn a light "on"

- Closed switch (both sides same voltage)
- Open switch (both sides can be different)
- A switch creates a path for electricity



Simple Circuit

- Every circuit needs three basic components:
  1. A voltage source
  2. A simple closed path
  3. A load
- The circuit must be closed for current to flow.

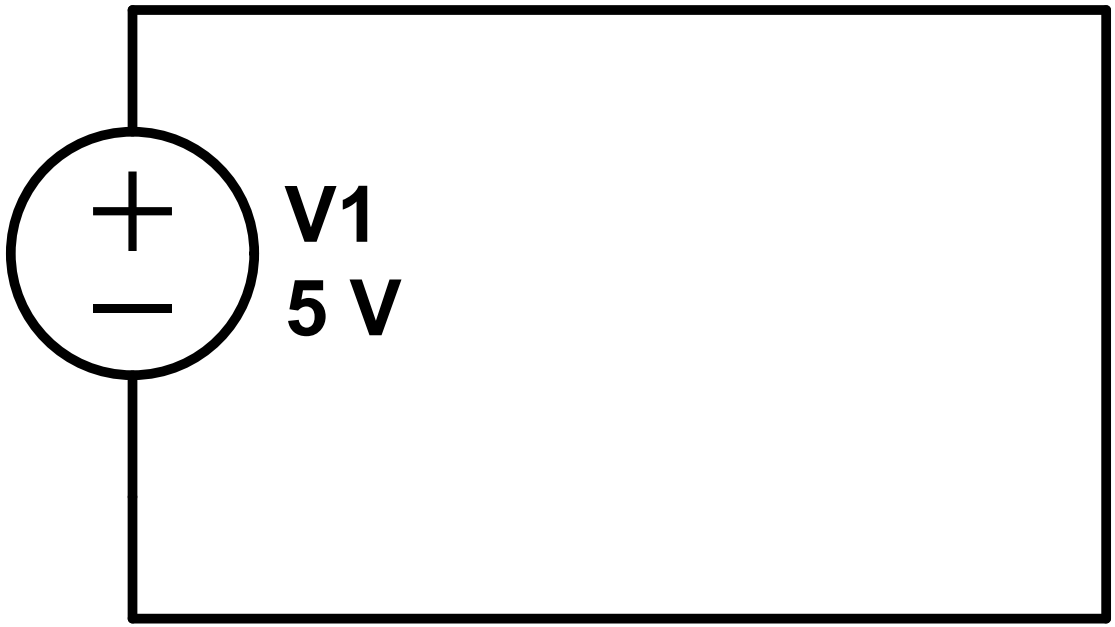


Example: Broken Circuit

- If the path is not closed the circuit is broken
- Without a closed path, electricity cannot flow.

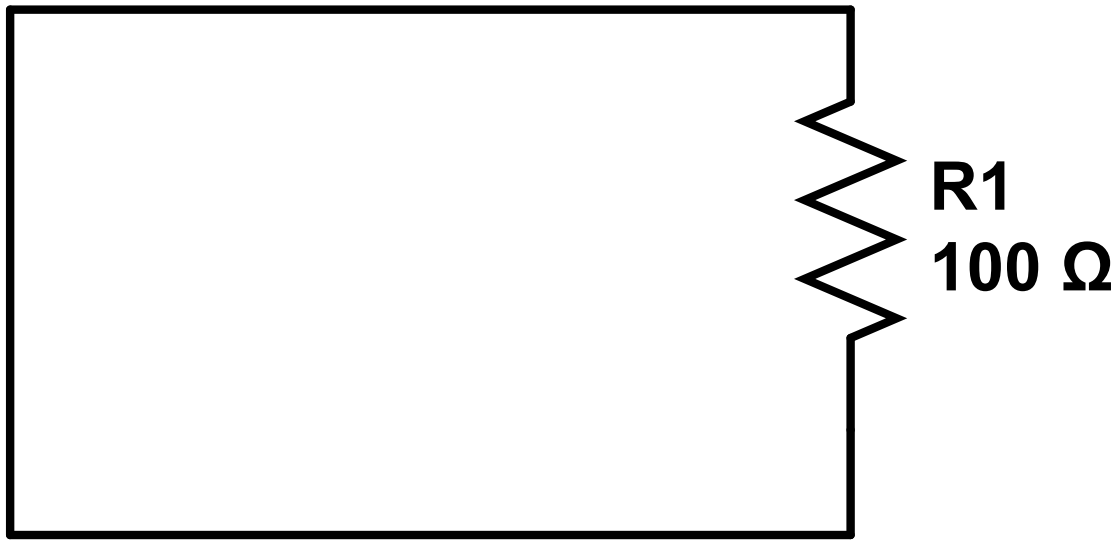
Example: Short Circuit

- A short circuit happens when the load is bypassed.
- Without the load, too much electricity flows.
- This can cause overheating and damage to the circuit.



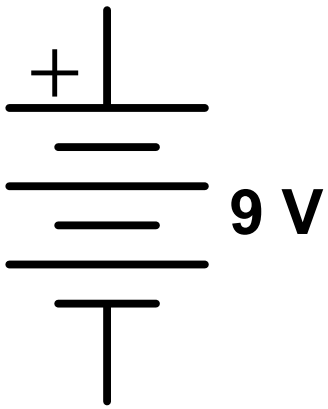
Example: No Voltage Source

- Without a voltage source, there is no reason for electricity to flow.
- The circuit remains inactive without a power supply.



Battery

- Converts chemical energy to electrical energy
- Provides a constant voltage source
- Essential for powering circuits



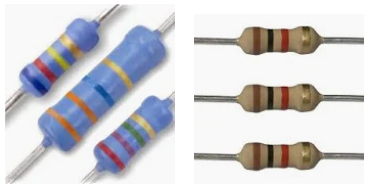
Schematic Symbol

Actual Device

Resistor

- A resistor restricts current
- Analogous to a pipe with friction
- Ohm's law: $V = IR$
- Power: $P = VI = I^2R$
- If you exceed the power rating, resistor can overheat

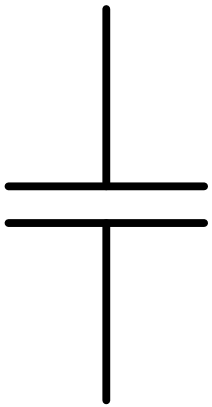
Schematic Symbol



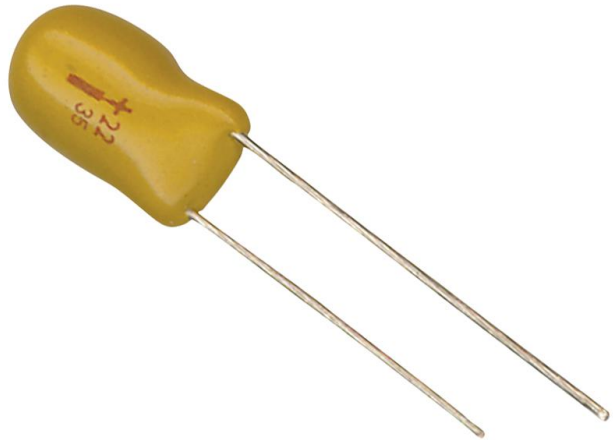
Actual Device

Capacitor

- Stores electrical energy as an electric field
- Used to smooth out voltage in circuits
- Capacitance measured in Farads (F)
- Analogous to a tire, too much pressure can blow it up!
- $E = \frac{1}{2}CV^2$



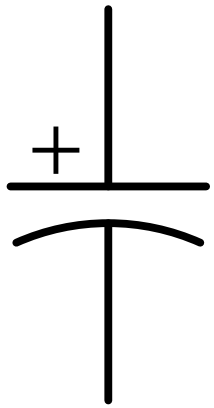
Schematic Symbol



Actual Device

Electrolytic Capacitor

- Polarized Capacitor
- Can blow up if voltage is applied in reverse
- Higher capacitance values than ceramic capacitors
- Commonly used in power supply filtering



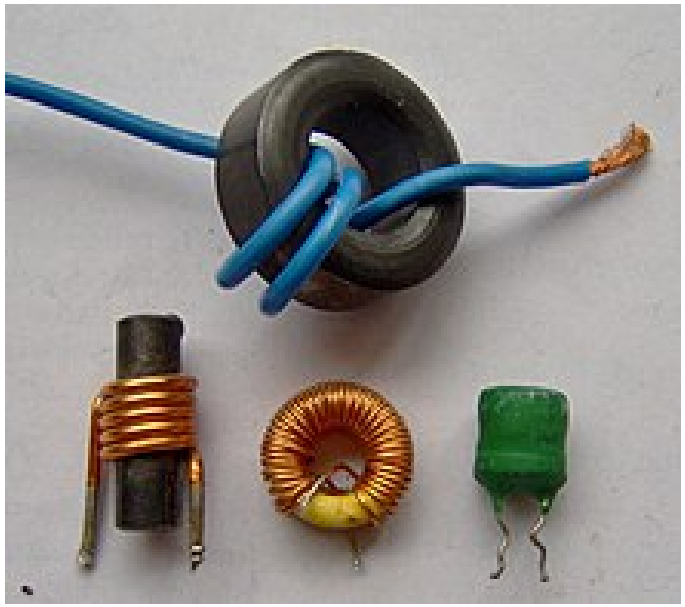
Schematic Symbol

Actual Device

Inductor

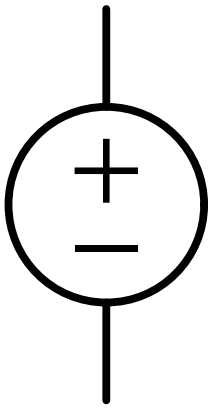
- Stores energy in a magnetic field
- Resists changes in current
- Commonly used in filters and power supplies
- Inductance measured in Henries (H)
- $E = \frac{1}{2}LI^2$

Schematic Symbol



Actual Device

Voltage Source



Schematic Symbol

Actual Device

SPST Switch

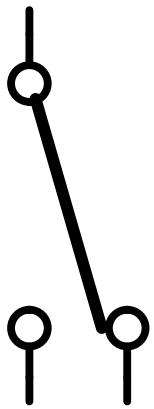
- Single Pole Single Throw (SPST)
- Simple on-off switch
- Connects or disconnects a single path

Schematic Symbol

Actual Device

SPDT Switch

- Single Pole Double Throw (SPDT)
- Directs current to one of two paths
- Used for selecting between two circuits

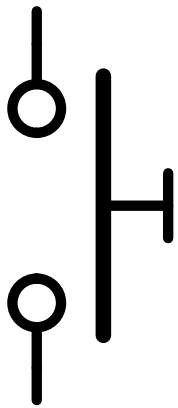


Schematic Symbol

Actual Device

Momentary On Pushbutton

- 4 pins
- When pressed, the wires are connected
- Each side is connected all the time
- The two sides are connected when the button is pressed



Schematic Symbol

Actual Device

Momentary Off Pushbutton

Schematic Symbol

Actual Device

Fuse

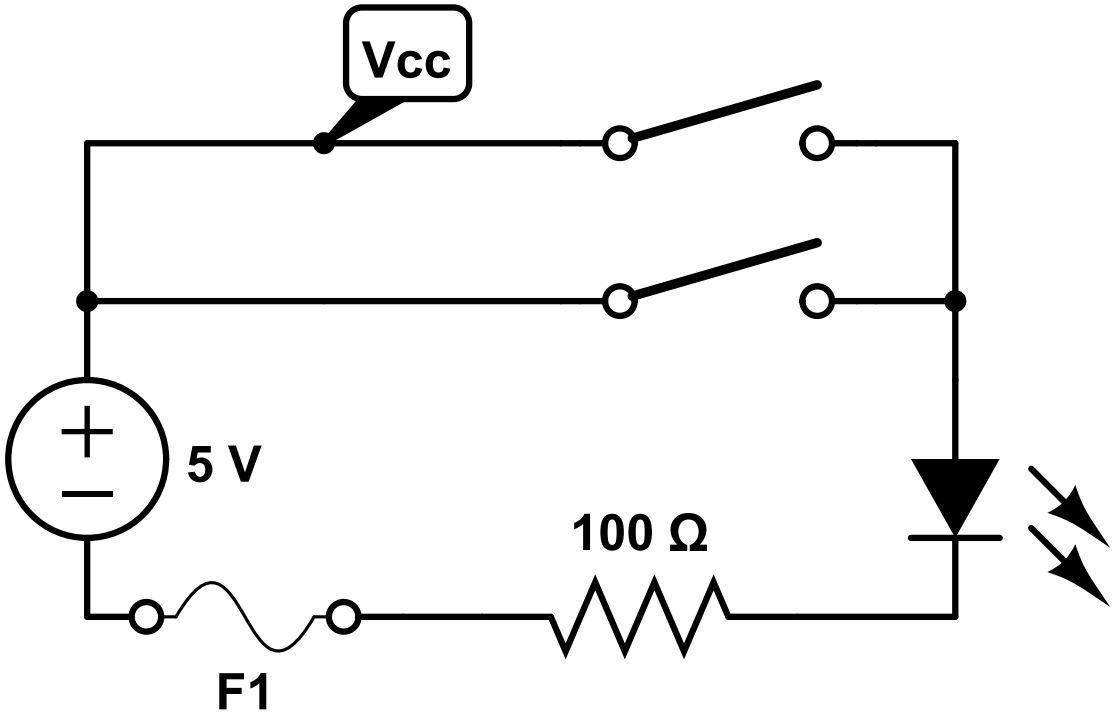
- A fuse is a safety device
- Protects electrical circuits from excessive current
- Thin wire or strip that melts when too much current flows through it
- The weakest link, breaking before the rest of the circuit

Schematic Symbol

Actual Device

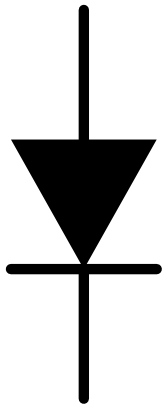
Using a Fuse

- Fuses must be in Series
- Should burn out before the rest of the circuit



Diode

- A diode allows current to flow in one direction
- Practically equivalent to a small resistor forward and large in reverse
- Has a low forward voltage drop and high reverse resistance
- Arrow is in the direction of positive current



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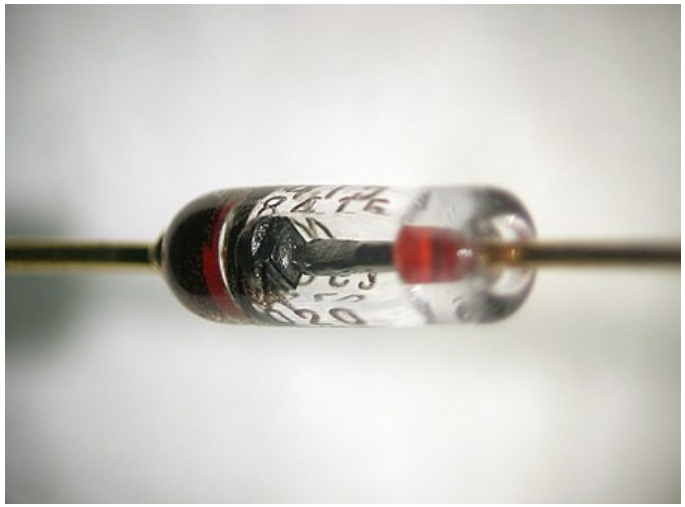
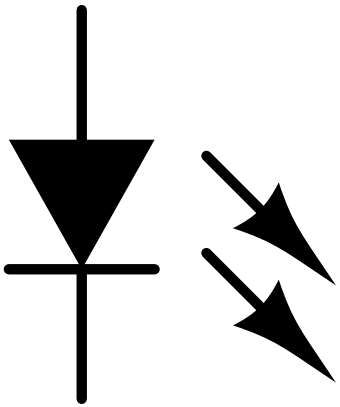


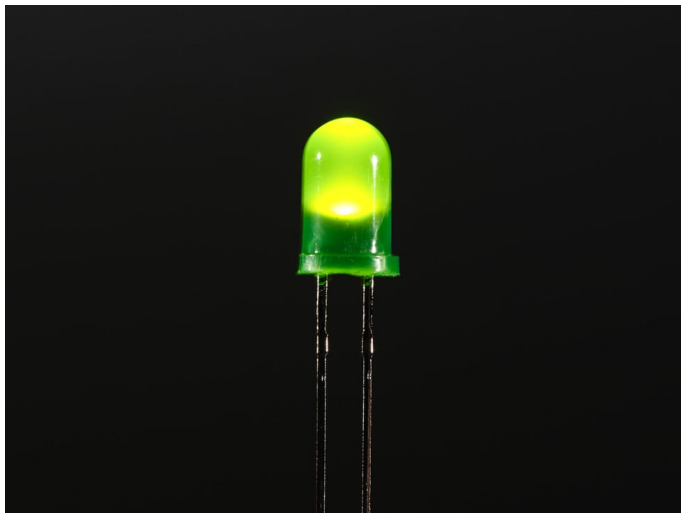
Actual Device

LED

- An LED is a special kind of diode
- Atomically tuned to emit light of one specific color
- Like any diode, current must flow forward
- Extremely little waste heat, highly efficient



Schematic Symbol



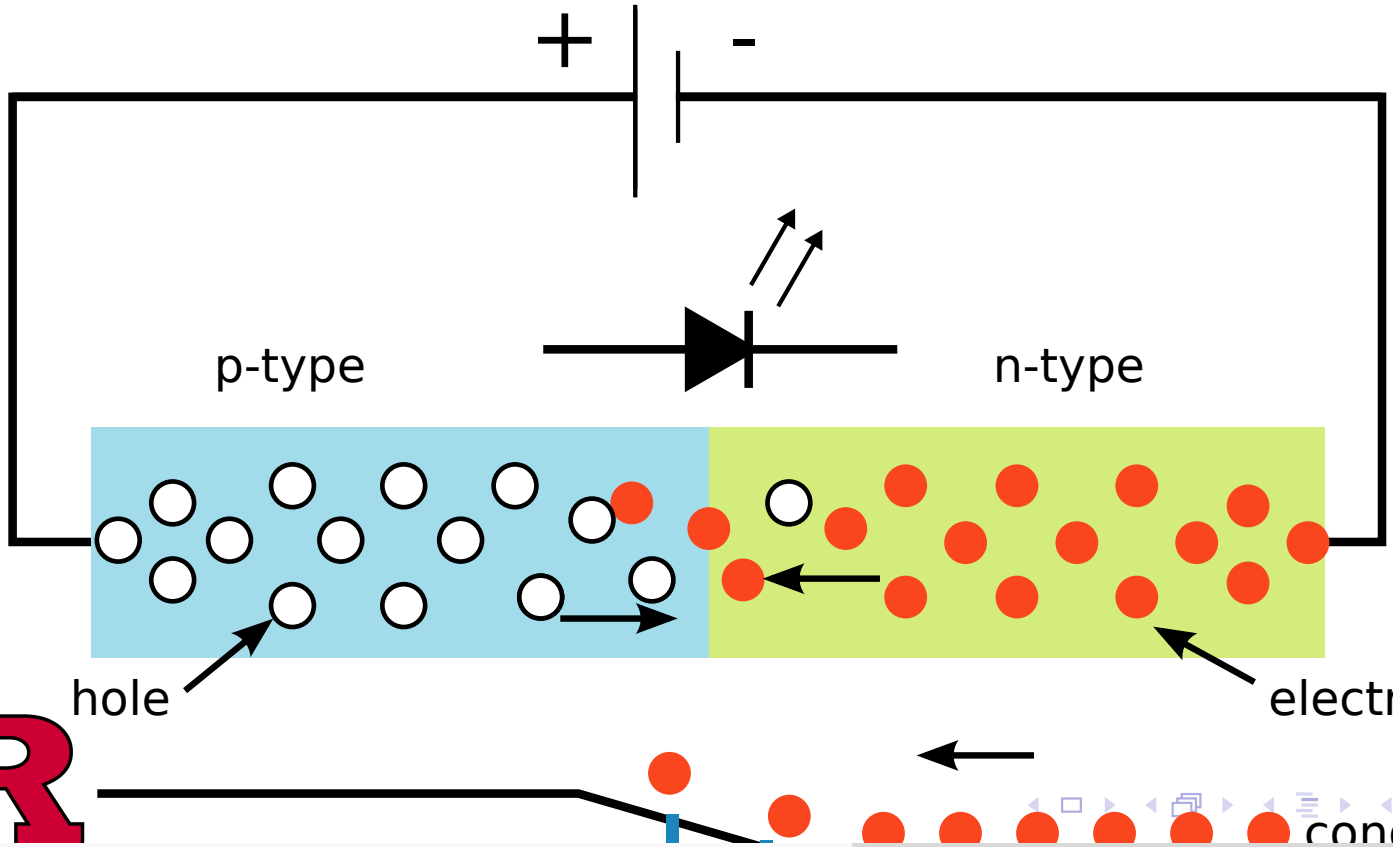
Actual Device

Conductors, Insulators, and Semiconductors

- A conductor (metals) has low resistance
- Outer electrons easily raised into conduction Background
- Insulators have very high resistance
- Very difficult to break electrons out of their orbits
- Semiconductors have medium resistance
- Extremely pure materials, doped with tiny amounts of other materials
- Silicon: 1 part per trillion (ppt) pure
- Doped with Boron and Phosphor (parts per billion (ppb))

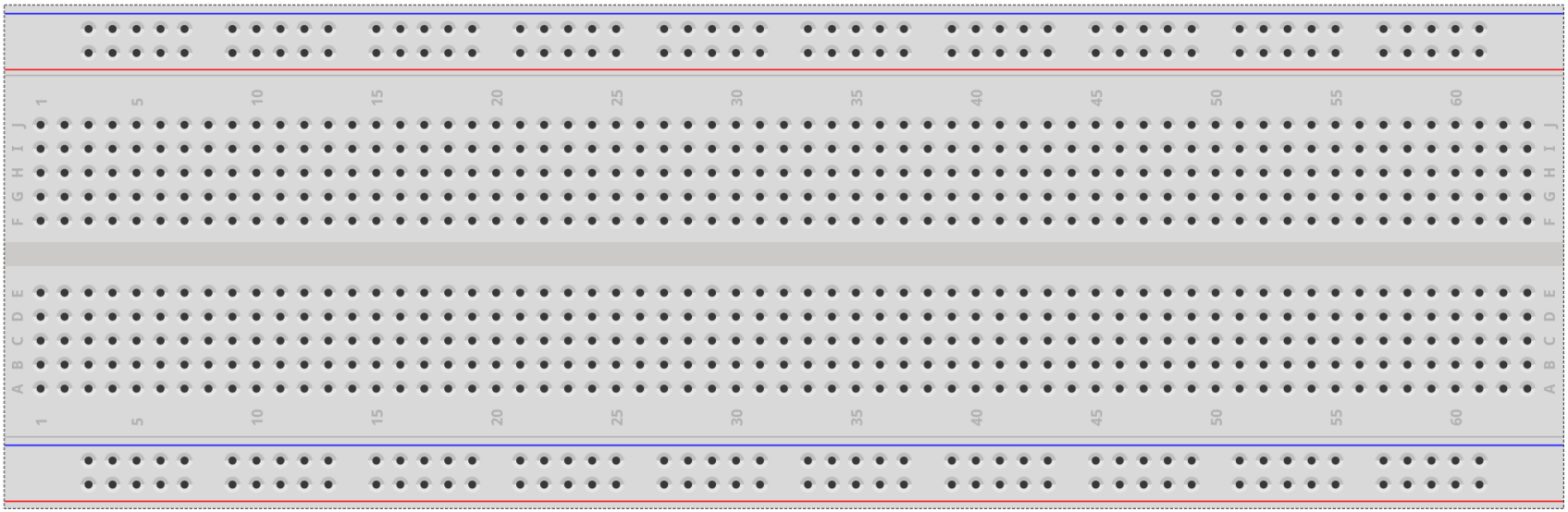
How does an LED Work?

- LEDs are doped with specific chemicals
- Each electron crossing the gap loses a precise amount of energy
- The color is determined by the energy gap between the two layers
- see `https://www.youtube.com/watch?v=JBtEckh3L9Q`

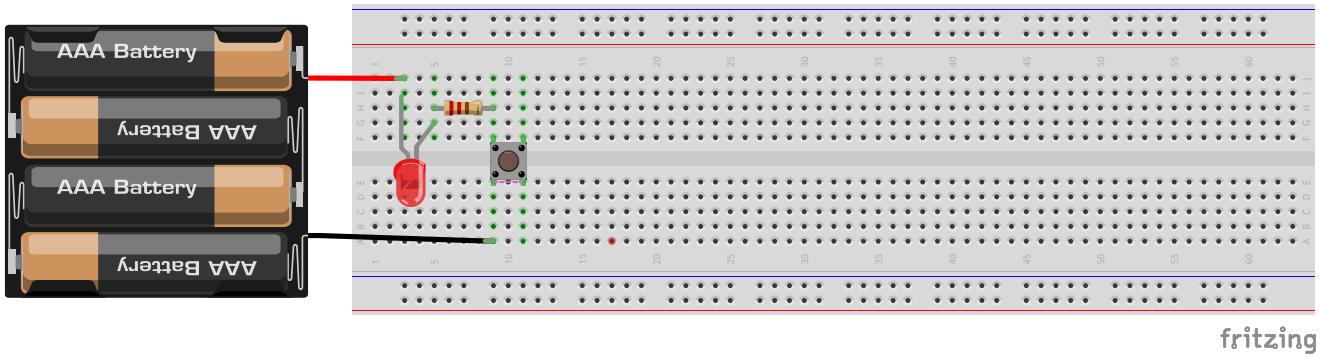


Breadboard Connections

- Power busses: vertical columns on edges
- Rows: horizontal lines for component connections
- Power distribution: busses connected along entire length
- Row connectivity: each row is electrically connected



Find the Bug



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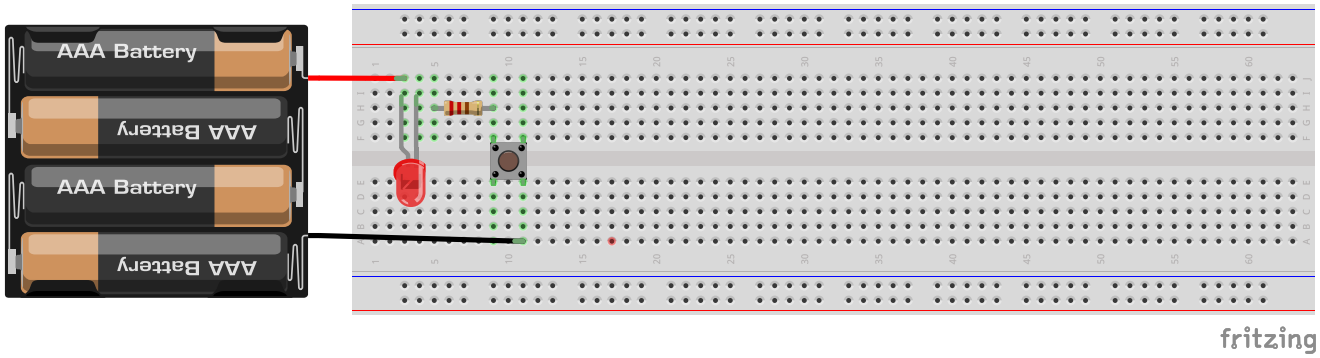

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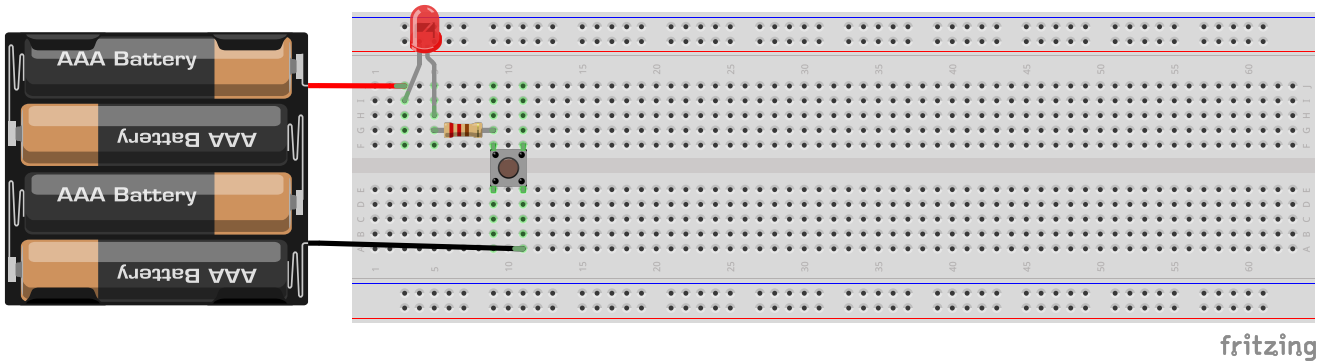

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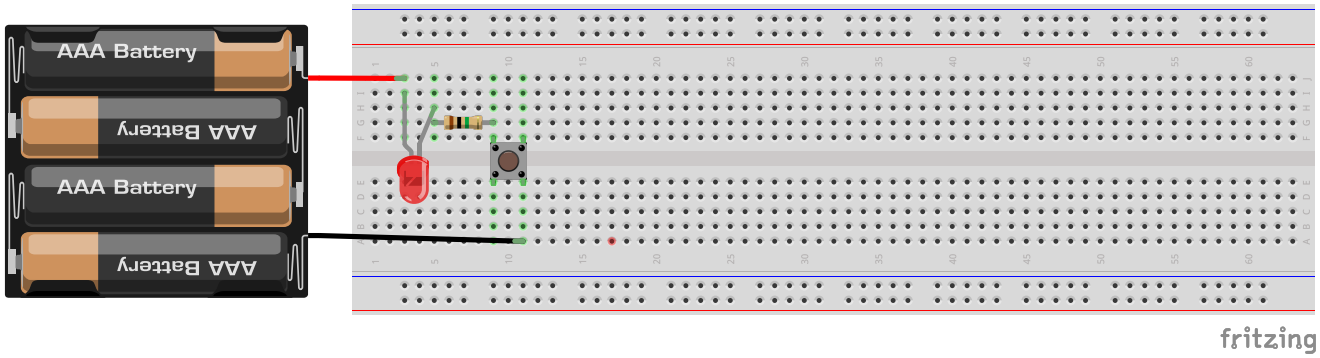

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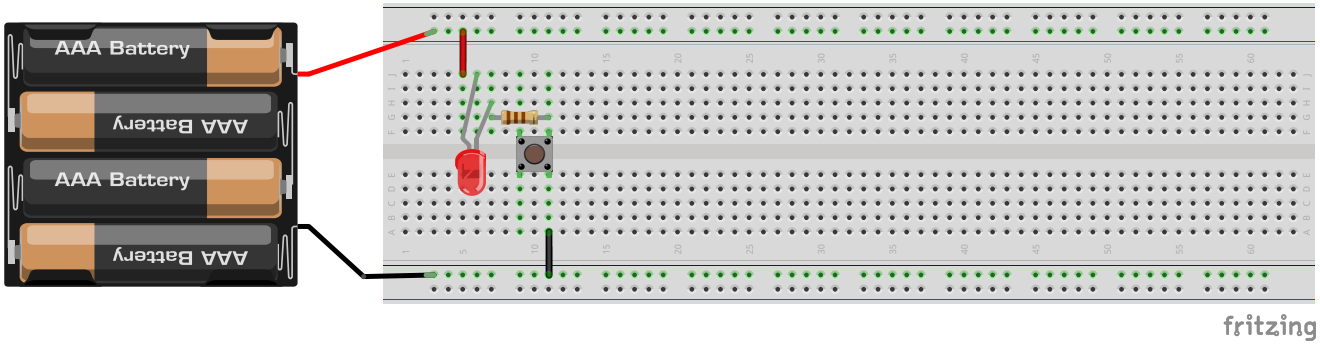

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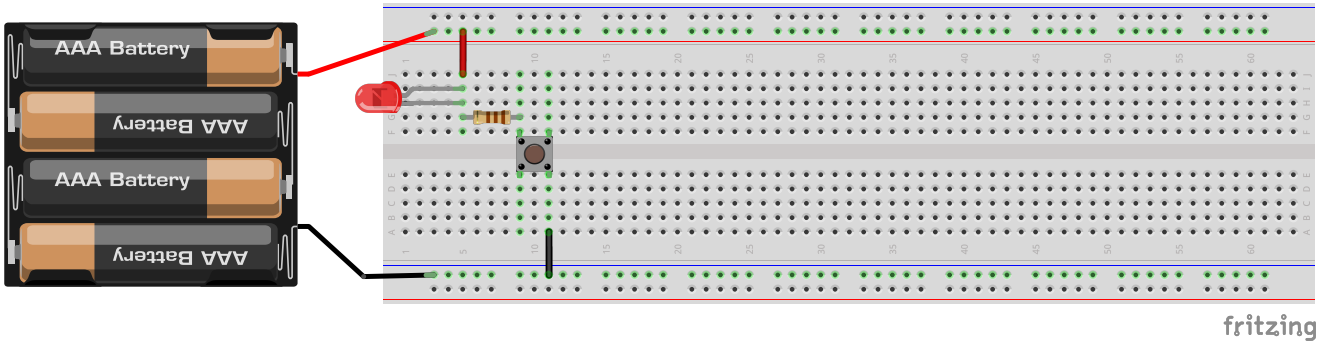

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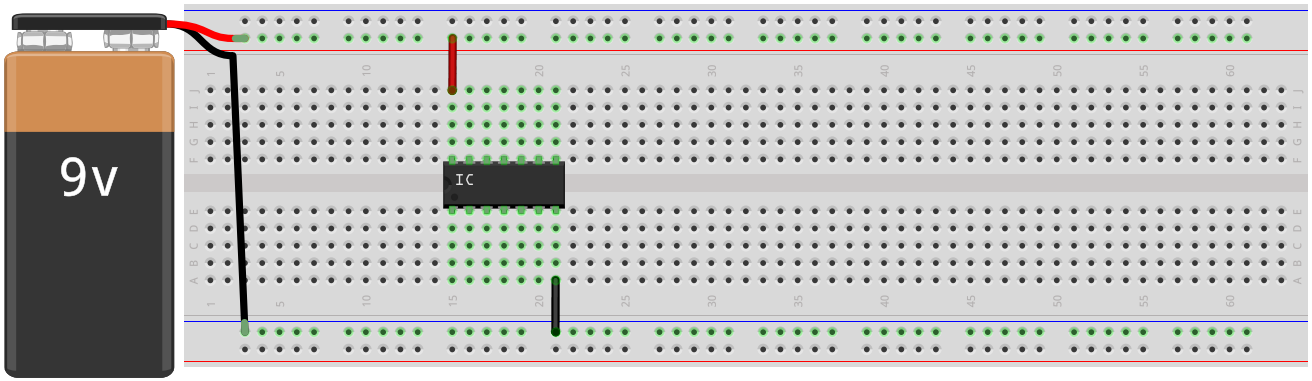

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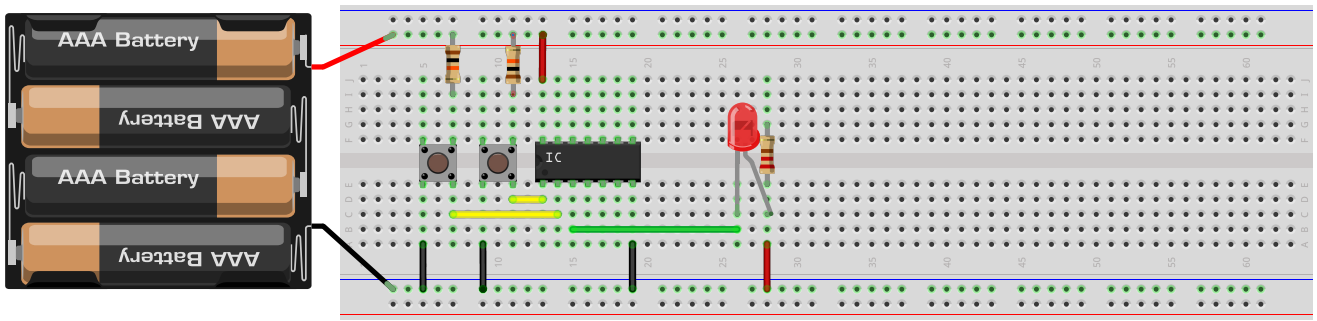

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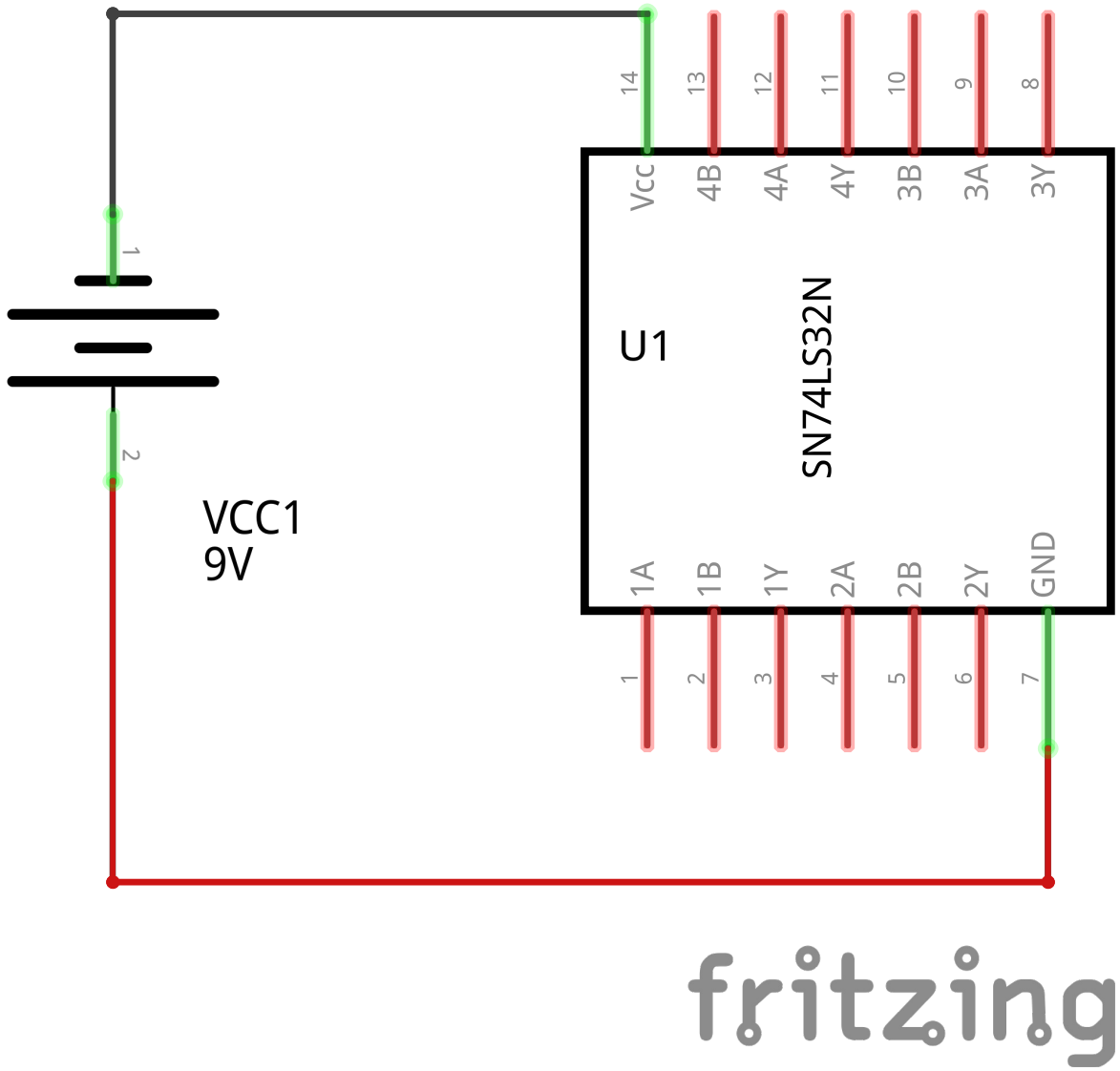

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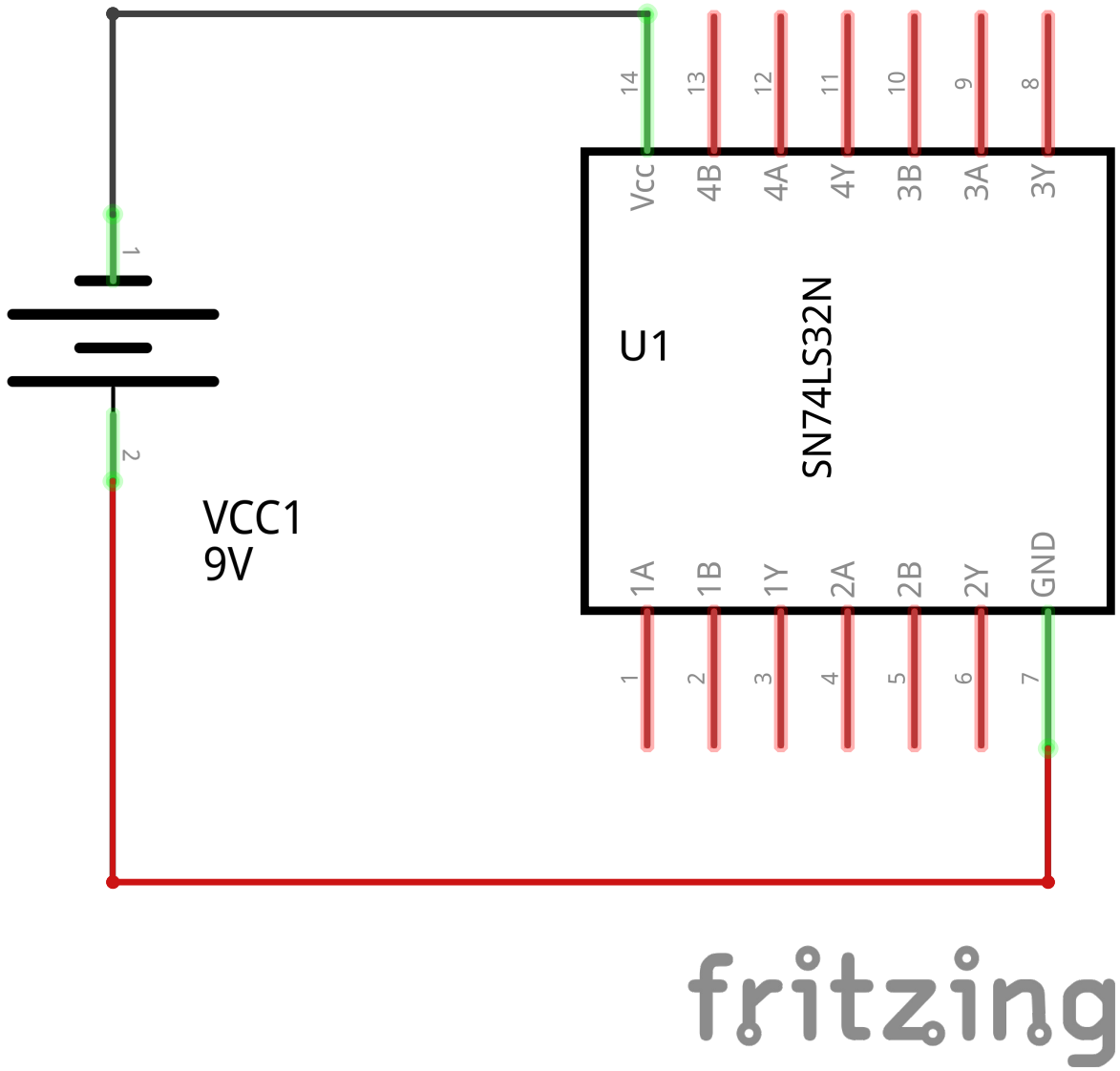
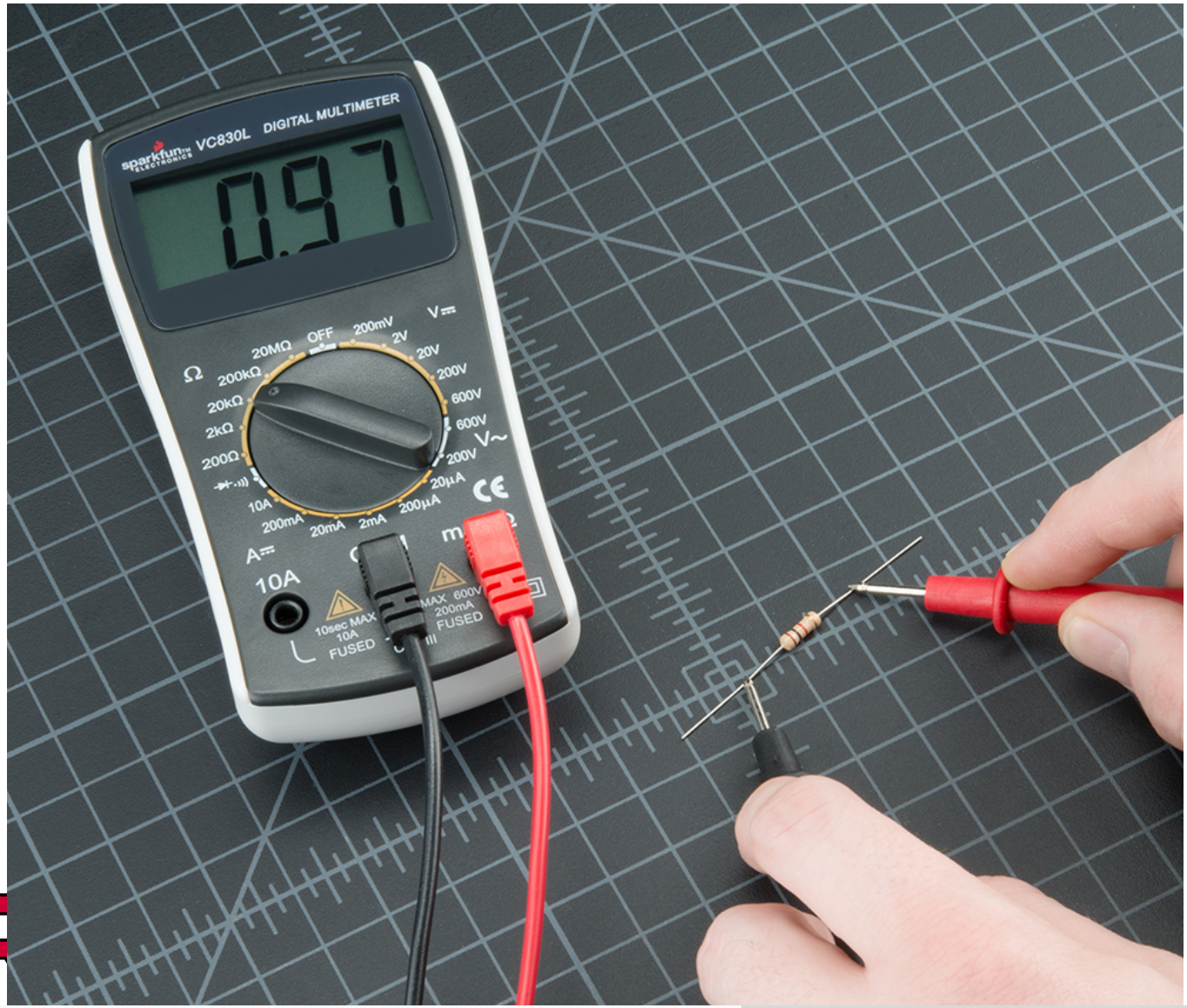


Introducing the DMM

Measuring Voltage

Measuring Resistance

- Manual range DMM
- Set to the smallest range larger than the resistor



How not to Measure Resistance

- What is