

Basic Circuits

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Basic Electricity

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

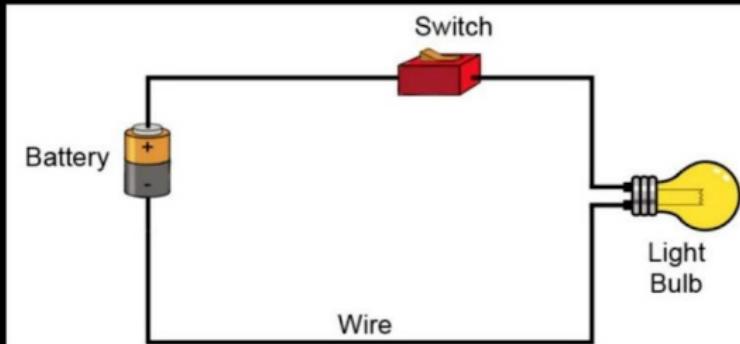
Electricity	Units	Abbrev	Hydraulic Analogy
Circuit			Water in a closed loop of pipe
Voltage	Volt	V	Water pressure
Current	Amps	A	flow
Power	Watt	W	Energy/time
Resistance	Ohms	Ω	Resistance to flow (friction)

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Basic Circuit

For anything to move, there must be a force. What is pushing the electricity around the circuit?

Electric Circuits



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Hydraulic Analogy

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

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

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Hydraulic Analogy Thought Questions

- What happens when you turn on the tap in your sink? Why?
- Where is the "circuit" when you open the tap in your sink?
- What happens if everyone in the city turns on the tap?
- The water main under the street may be 8 inches
 - Why are the pipes in your house 1 inch or $\frac{3}{4}$?
 - What would happen if your sink had an 8 inch pipe and you turn it on?

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

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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
Tera	T	10^{12}
bottomrule		

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Units with Prefixes

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

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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: $V = I \cdot R$

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

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- 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

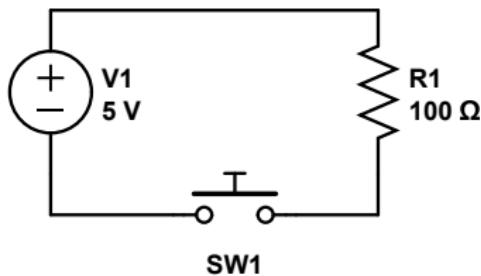
- Digital is a simplified abstraction of Circuits
- We consider only high (V_{cc}) or low (0V)
- High (1) and Low (0)
- Any extraneous signal (noise) can be ignored
- Theoretically instantaneous

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Correct Terminology: Forget "on" and "off"

Turn a light "on"

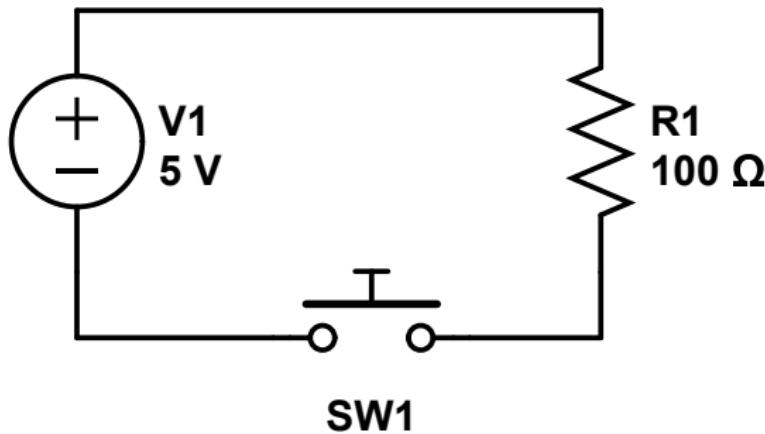
- Closed switch (both sides same voltage)
- Open switch (both sides can be different)
- A switch creates a path for electricity



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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.



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Example: Broken Circuit

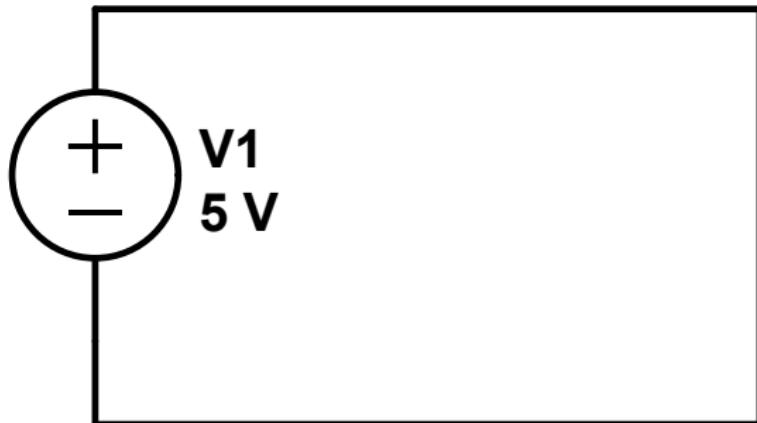
- If the path is not closed the circuit is broken
- Without a closed path, electricity cannot flow.



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Example: Short Circuit

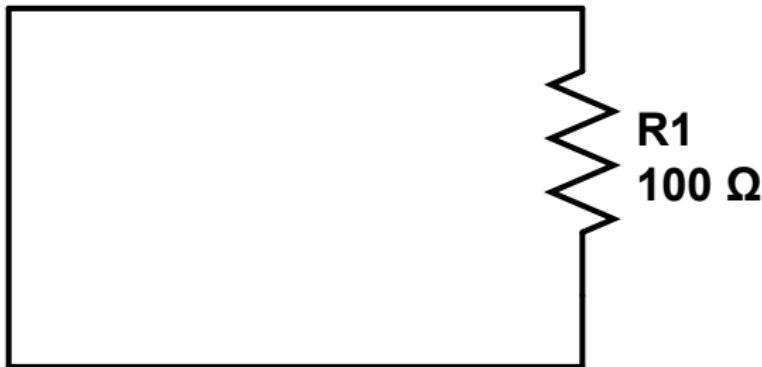
- A short circuit happens when the load is bypassed.
- Without the load, too much electricity flows.
- This can cause overheating and damage to the circuit.



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Example: No Voltage Source

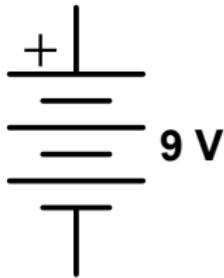
- Without a voltage source, there is no reason for electricity to flow.
- The circuit remains inactive without a power supply.



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Battery

- Converts chemical energy to electrical energy
- Provides a constant voltage source (ahem... not really?)
- Essential for powering circuits



Actual Device

Schematic Symbol

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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



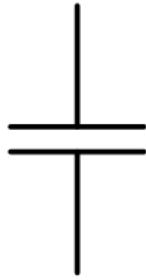
Actual Device

Schematic Symbol

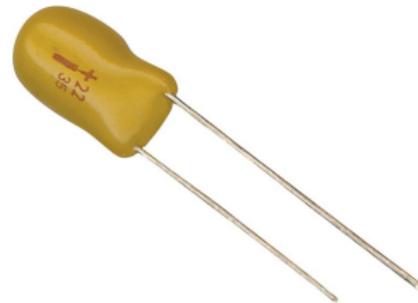
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Capacitor

- 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

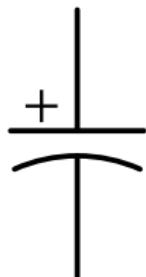


Actual Device

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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

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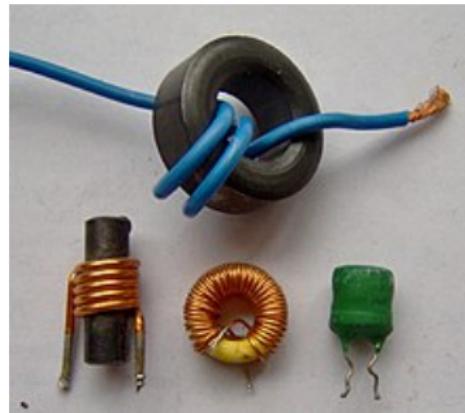
Inductor

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



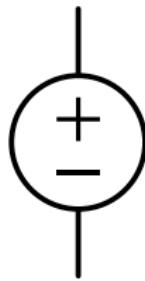
Schematic Symbol

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Actual Device

Voltage Source



Schematic Symbol

Actual Device

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SPST Switch

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



Schematic Symbol



Actual Device

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SPDT Switch

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



Schematic Symbol

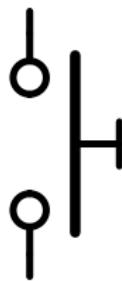


Actual Device

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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

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Momentary Off Pushbutton



Schematic Symbol

Actual Device

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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



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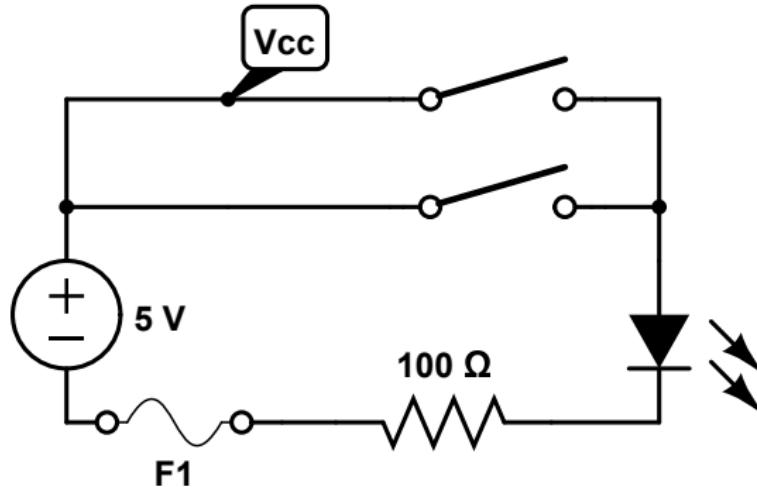
Schematic Symbol



Actual Device

Using a Fuse

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



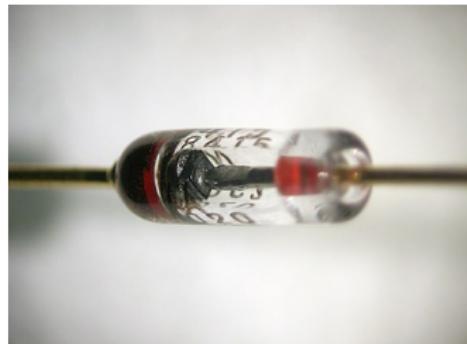
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Diode

- 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



Schematic Symbol

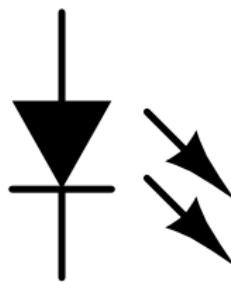


Actual Device

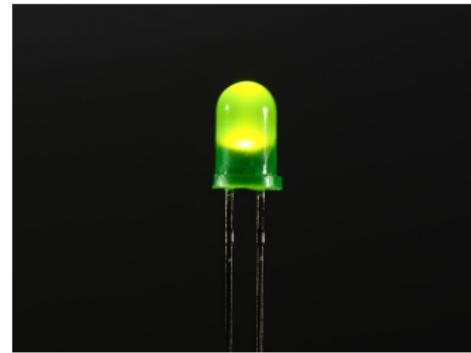
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LED

- 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

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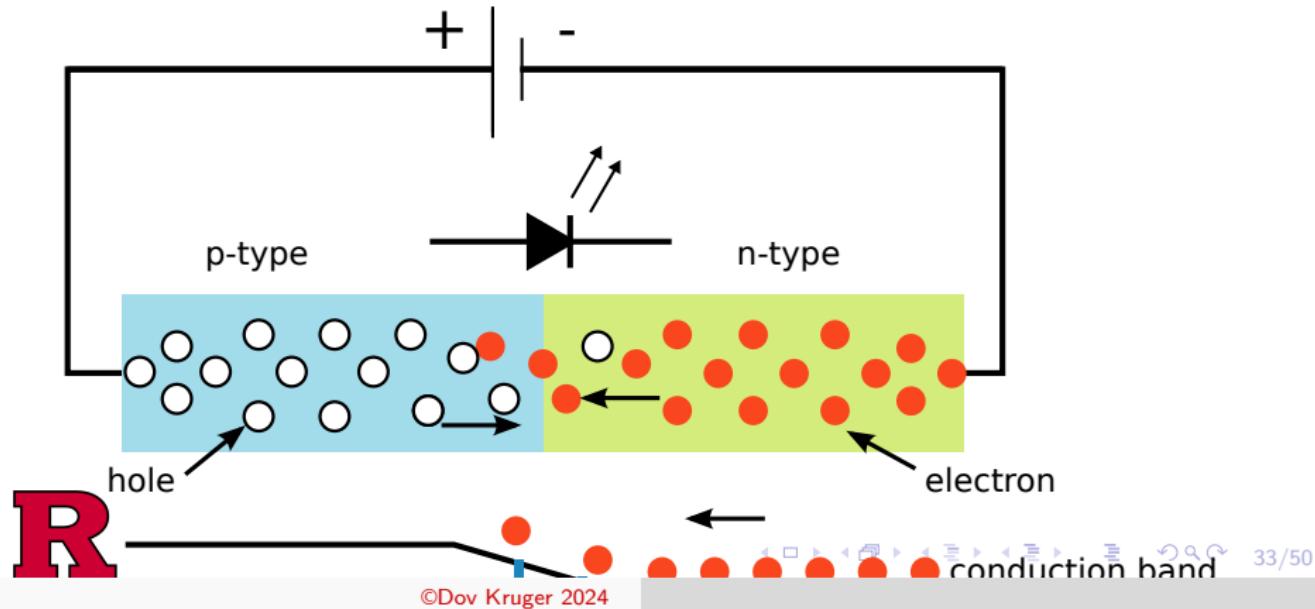
Conductors, Insulators, and Semiconductors

- 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))
- Even doped, a semiconductor is not a great conductor
- But it can change radically with temperature, light, etc.

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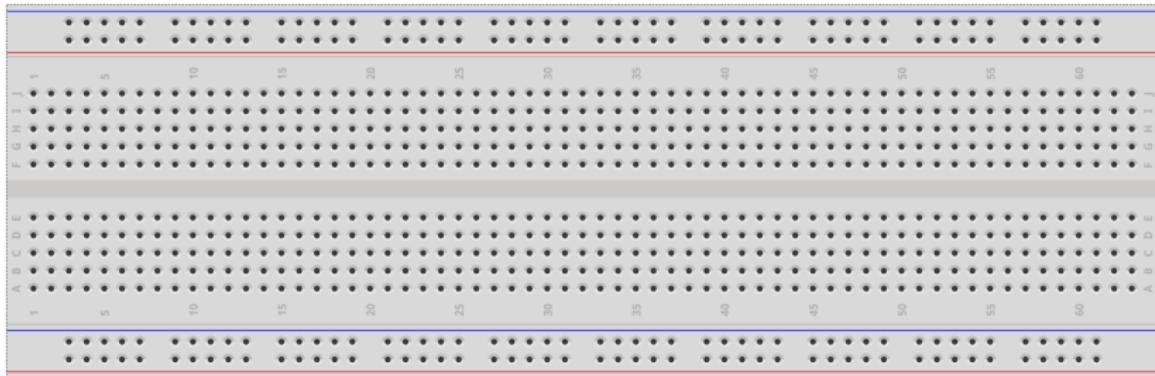
How does an LED Work?

- 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>



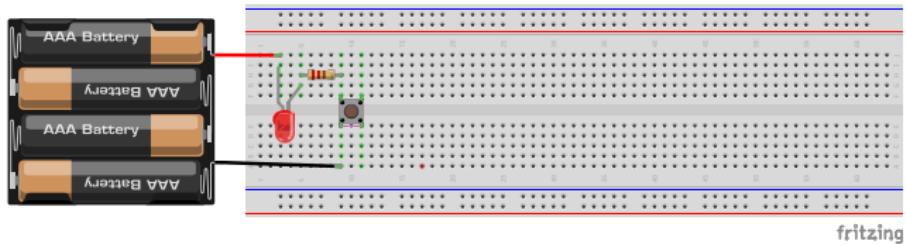
Breadboard Connections

- 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



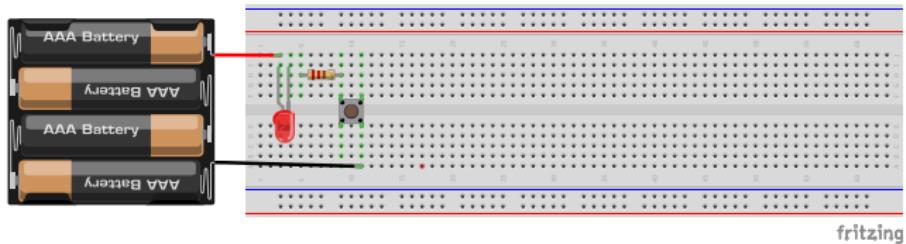
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Find the Bug



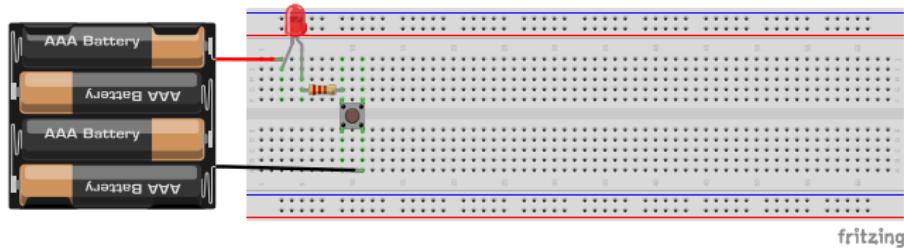
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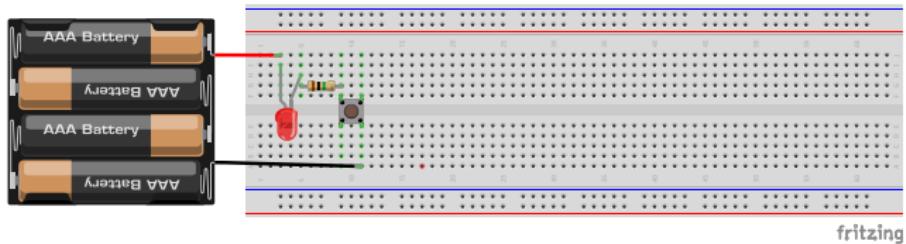
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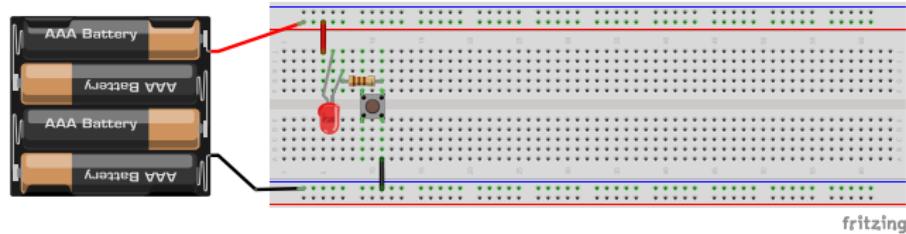
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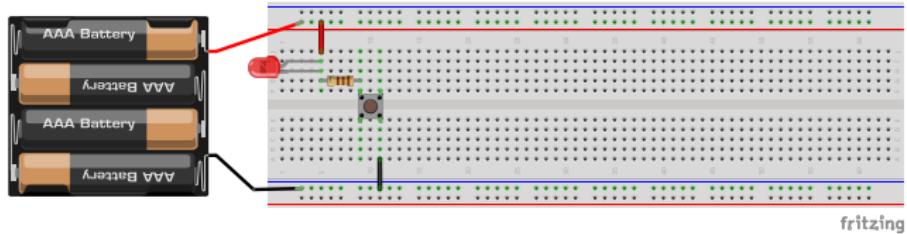
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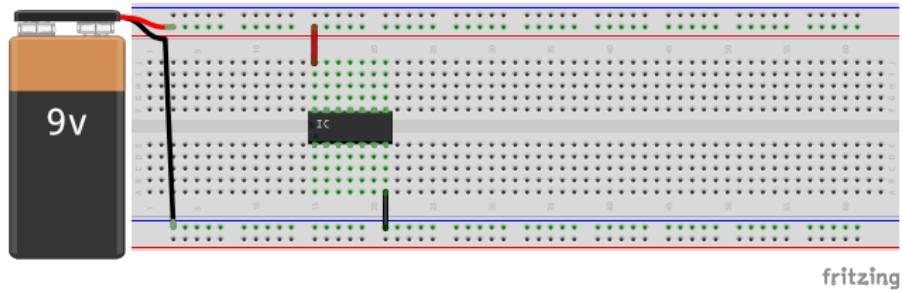
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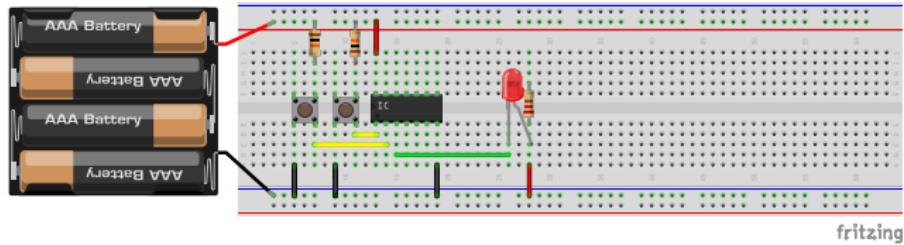
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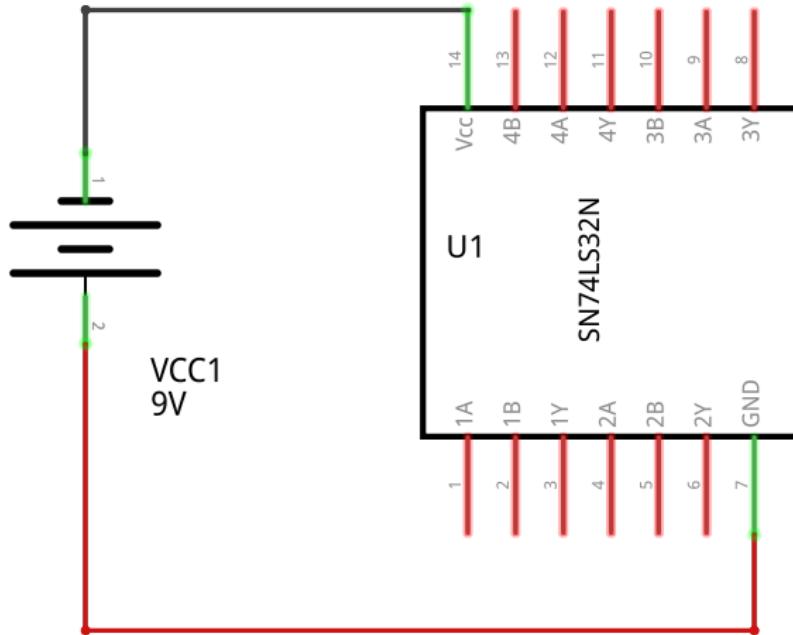
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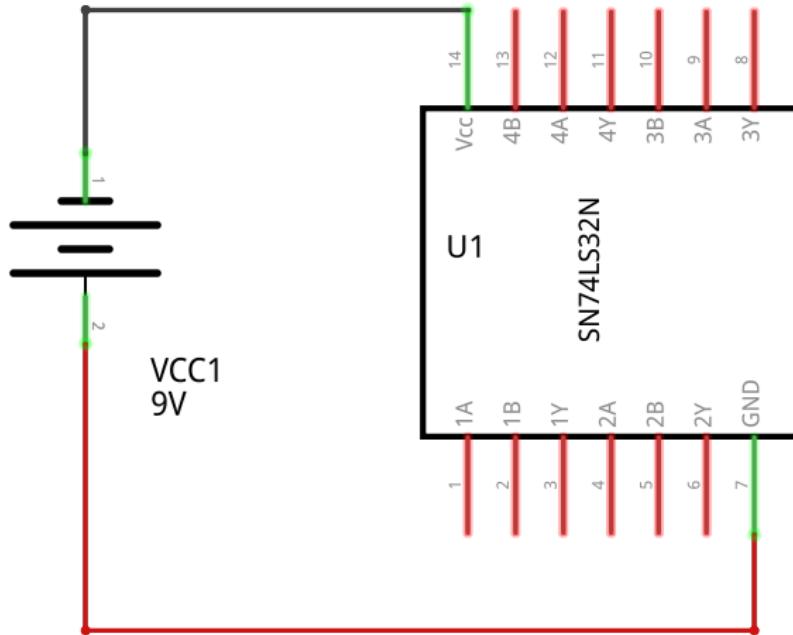
Find the Bug



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Find the Bug



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Domains of Electronics

- Small Signal DC
- AC Power
- RF (Radio Frequency)
- Ultrafast EMP (Electromagnetic Pulse)

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Small Signal DC Assumptions

- All wires have zero resistance
 - all points on a wire are the same voltage
- Circuits turn on immediately (no delay due to capacitance or inductance)
- Voltage sources are ideal (no internal resistance)
- No significant heating effects in components
- No signal degradation or noise

Analyze the Voltages on the in-class Worksheet

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Introducing the DMM



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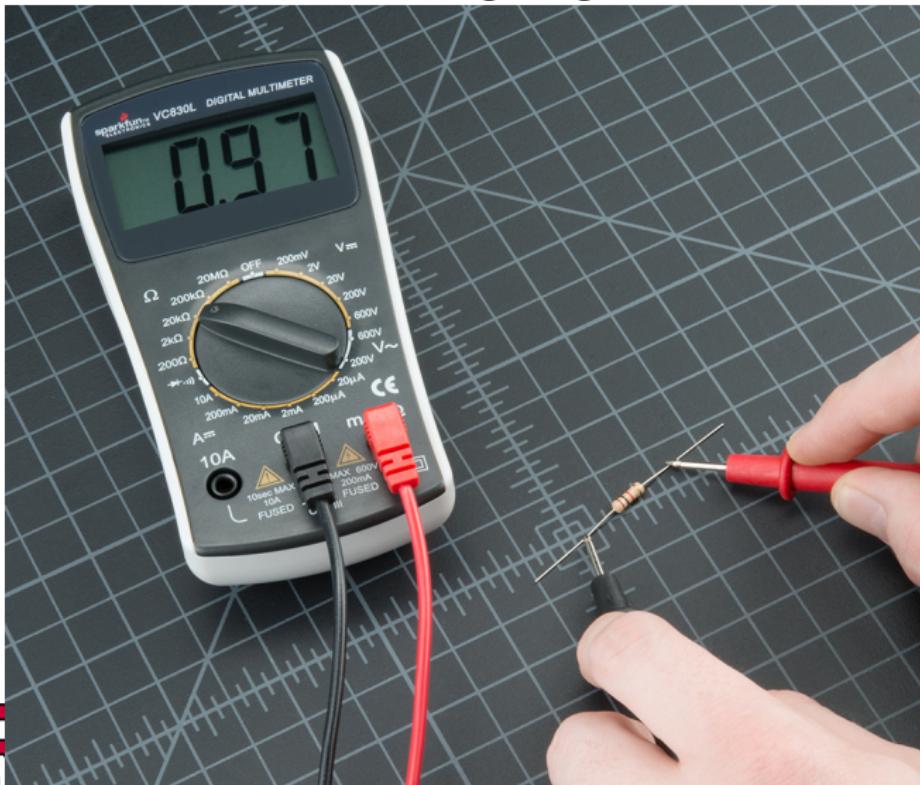
Measuring Voltage



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Measuring Resistance

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



How not to Measure Resistance

- What is wrong with this picture?



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