NYU TANDON SCHOOL OF ENGINEERING

Promoting robotic design and entrepreneurship experiences among students and teachers

Lesson 4: Basic Electronics

Innovative Technology Experiences for Students and Teachers (ITEST), Professional Development Program, July 2017-19

Mechatronics, Controls, and Robotics Laboratory, Department of Mechanical and Aerospace Engineering, NYU Tandon School of Engineering

CONTENTS

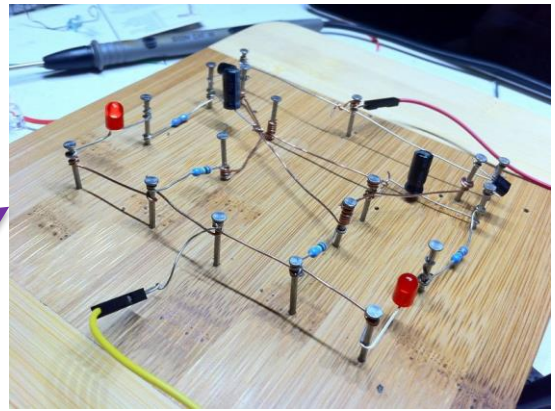
- Breadboarding circuits
- What is electricity
- Voltage, current, resistance
- Ohm’s law, circuit basics
- Electronic components
- Analog and digital signals
- Digital electronics (logic gates)

THE BREADBOARD

- A breadboard is a thin-plastic board used to hold and connect electronic components and/or wires temporarily
- It is used for **circuit prototyping**, i.e., building an actual circuit to verify a theoretical circuit design

Years ago:

Source



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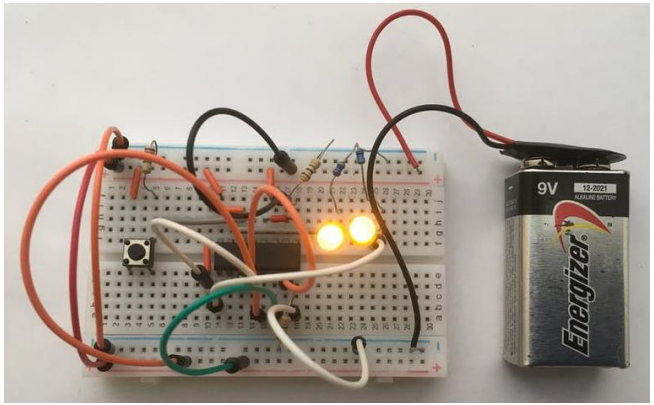
Now:



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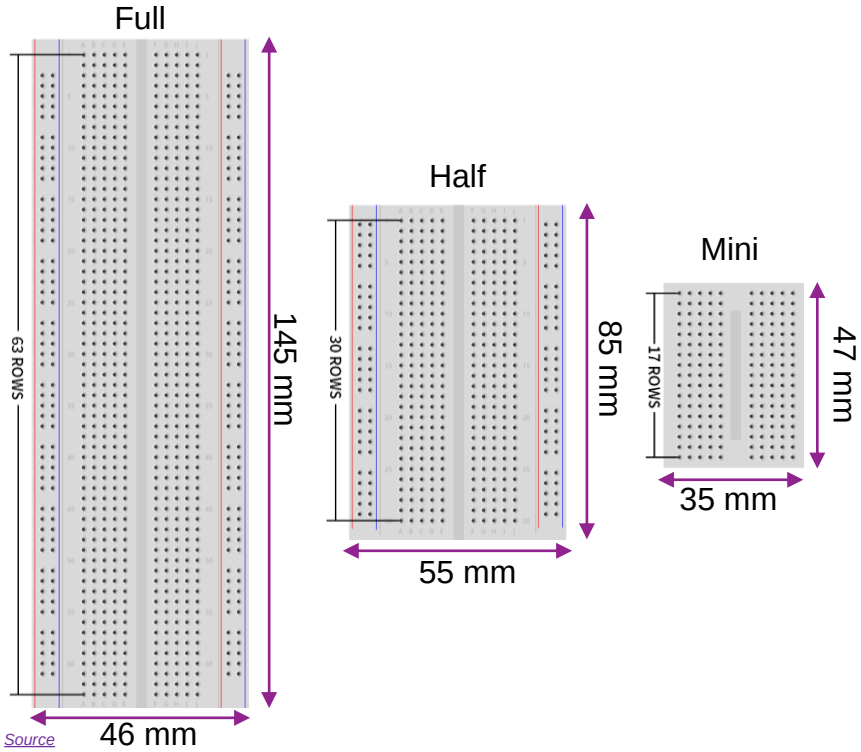
THE BREADBOARD



Source

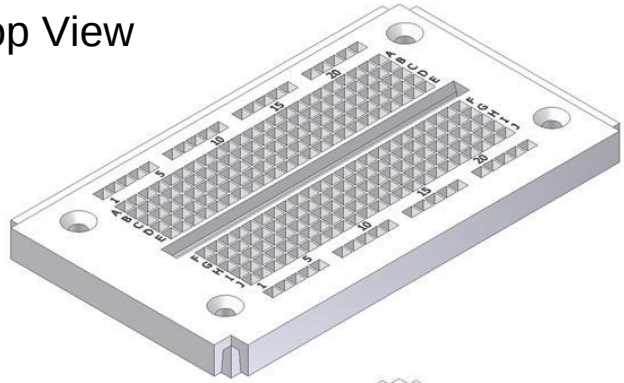
Common sizes of breadboards

Video

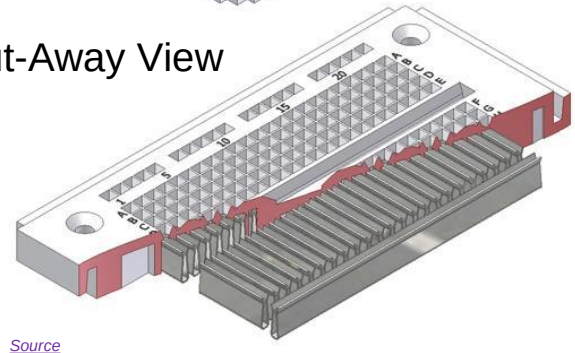
HOW A BREADBOARD WORKS

- The surface of the breadboard has **holes** arranged in a grid pattern
- Electric component **leads and the wires** used to connect them are inserted into these holes
- A series of internal **metal strips** serve as jumper wires, they connect specific rows of holes

Top View



Cut-Away View



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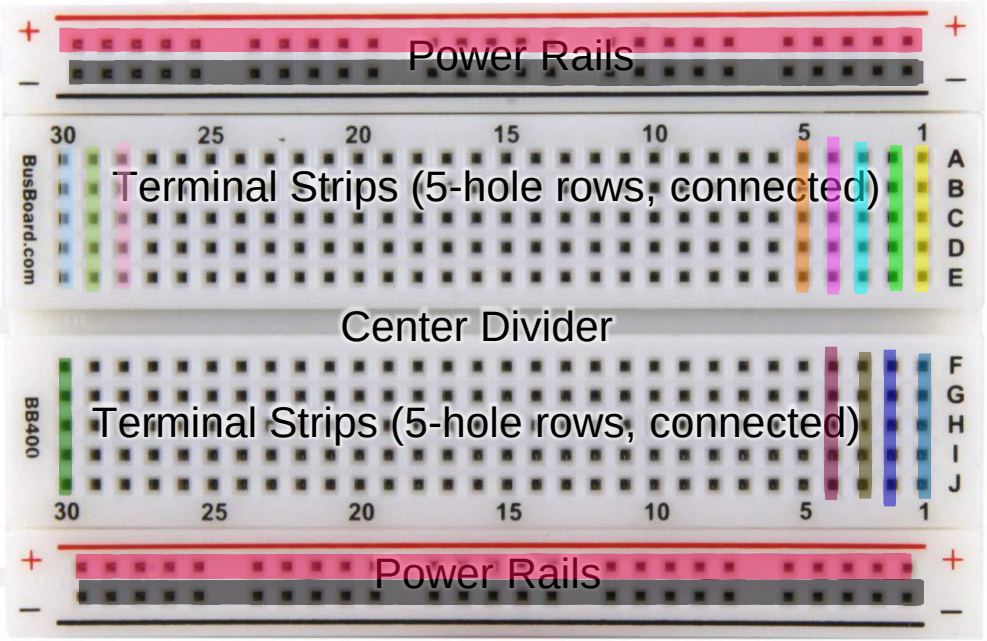
BREADBOARD CONNECTIONS

1-30 are connected (even along the breaks, for example, between 5 and 6)

A-E and F-J are connected internally (but not across the middle divider, i.e., not between E & F)



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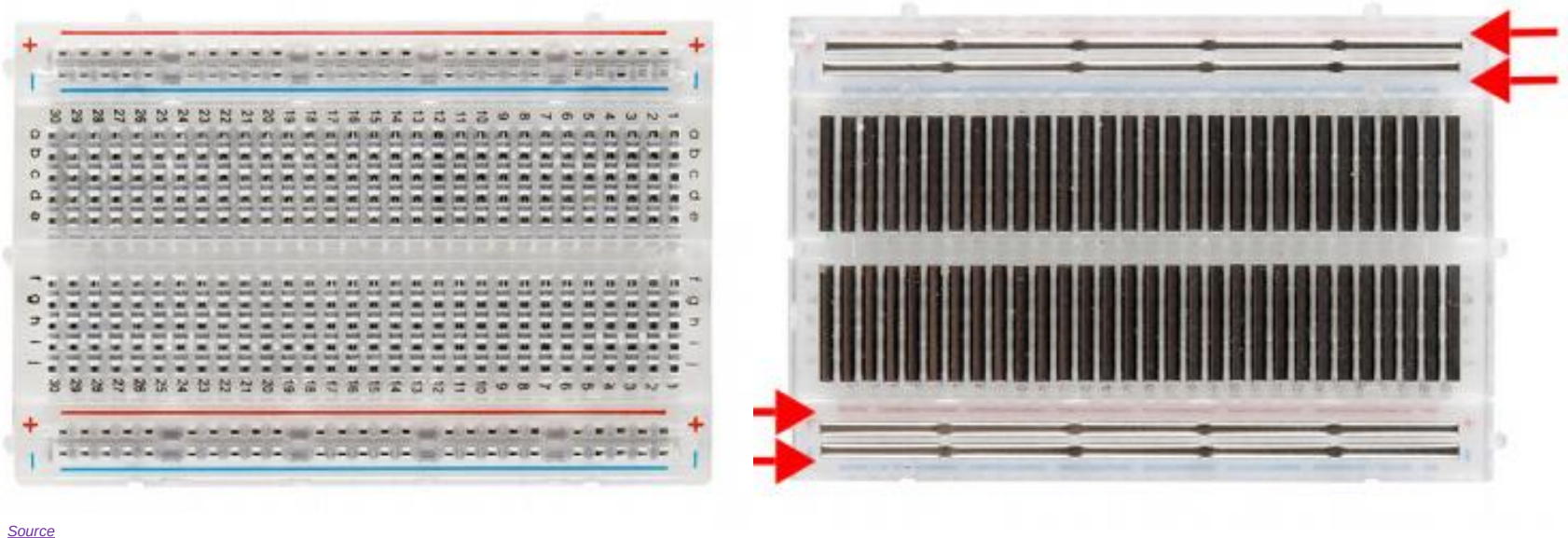
NOTE: Same colored rows are connected internally

BREADBOARD CONNECTIONS

Inside a breadboard



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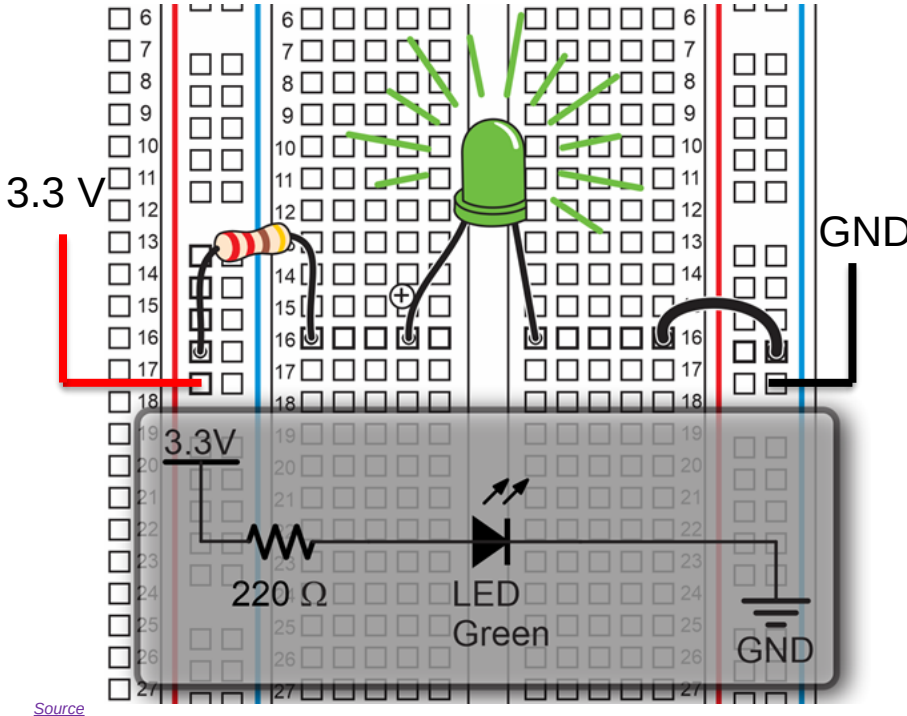
BREADBOARD: GUIDELINES AND TIPS

To make troubleshooting easier:

- Use the breadboard to connect majority of the components
- **Use as few jumper wires** as possible
- Keep jumper wires **short** to help avoid a jumble of wires
- Make connections to **resemble the circuit schematic** as close as possible



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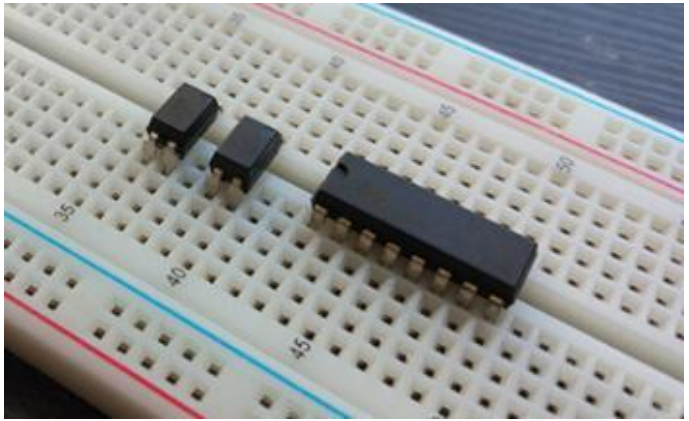
Breadboard circuit ~ schematic circuit

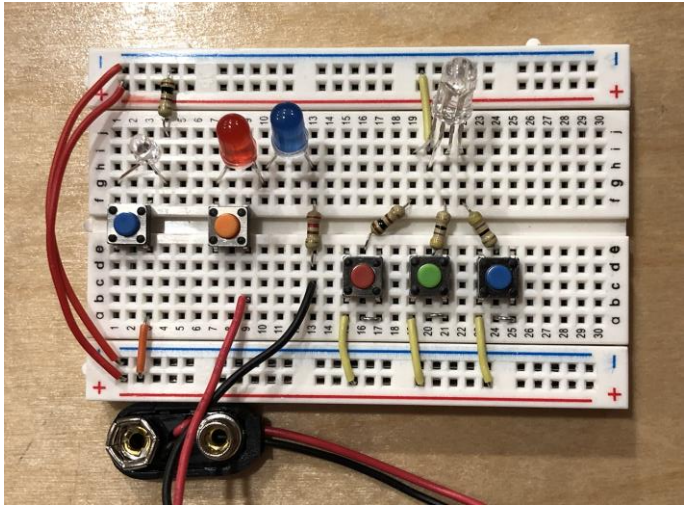
BREADBOARD: GUIDELINES AND TIPS

- **IC chips** must be the middle of the breadboard, as shown below.



Source

- **Cut component leads** to manageable lengths, to avoid short circuit and maintain a clean circuit.



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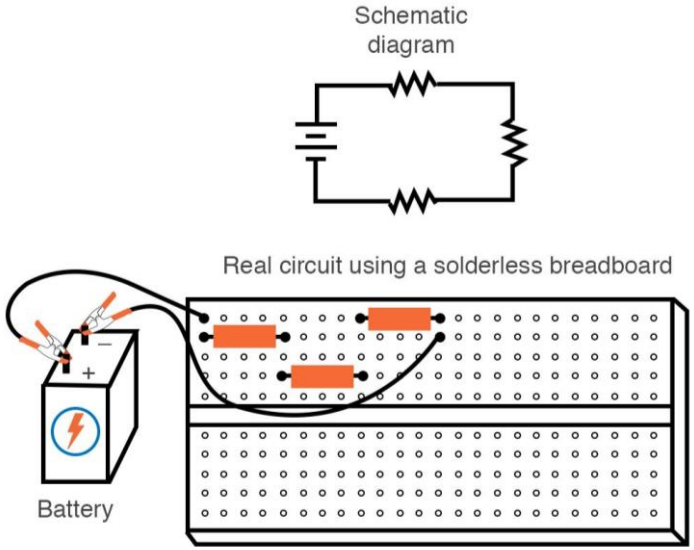
BREADBOARD: GUIDELINES AND TIPS

- Work from a circuit **schematic** and check off the connections on the breadboard one by one

- Have someone **check** your circuit for errors



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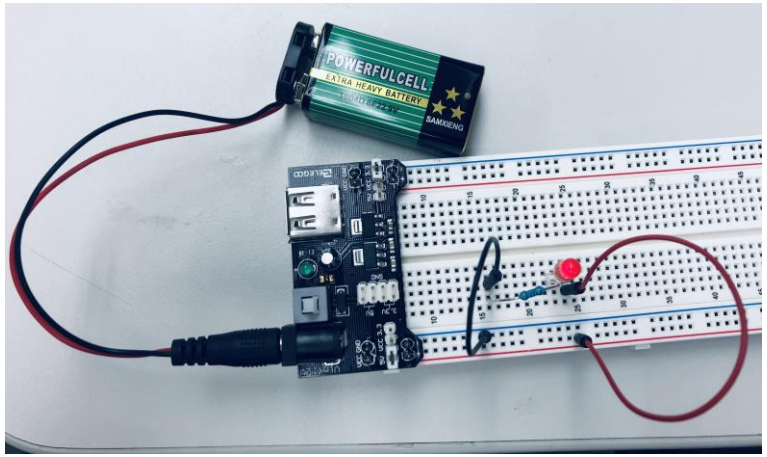
POWER SUPPLY MODULE



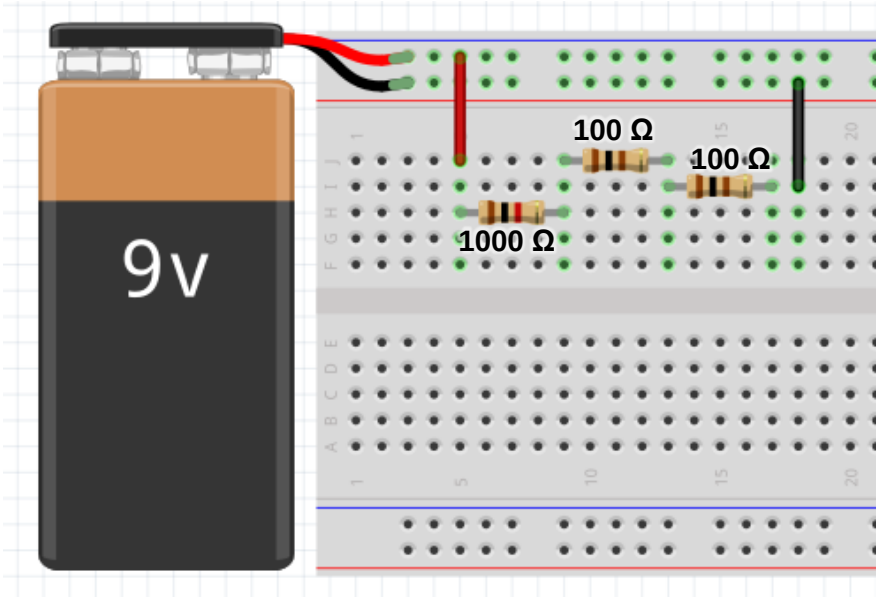
Input Voltage : DC 6.5 -12V

Output Voltage : DC 3.3V - 5V

Instead of directly powering the breadboard using a battery and connector (without barrel plug),

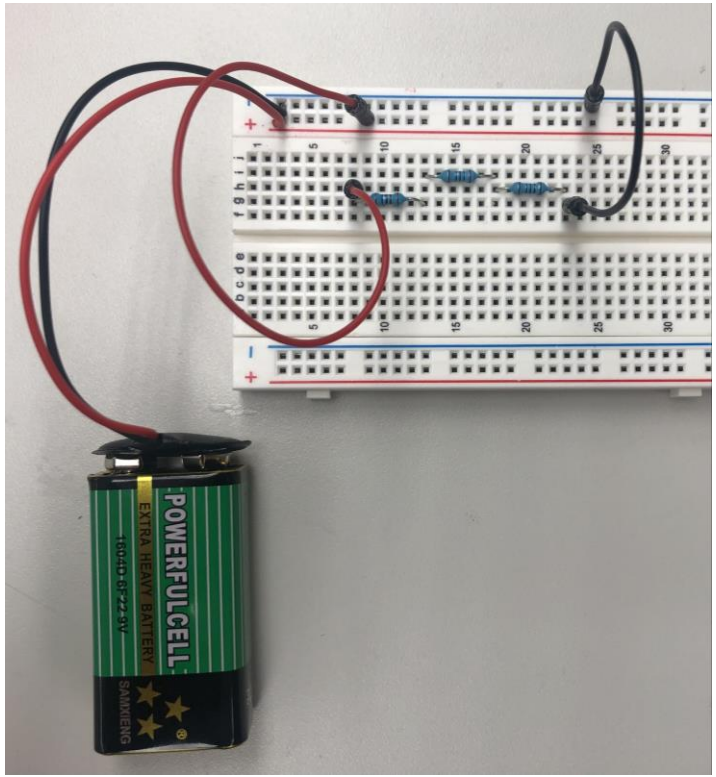
A **power supply module** can be used to supply a constant voltage of 5V to the breadboard using a **battery connector (with barrel plug)**

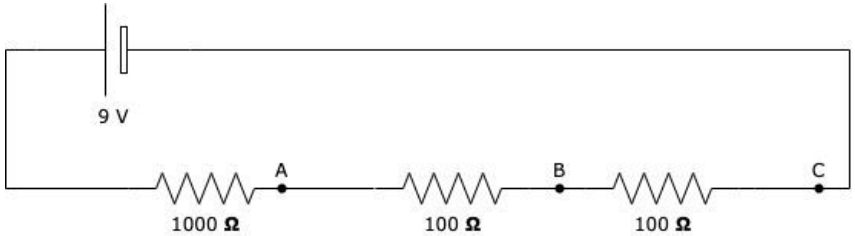
ACTIVITY - I



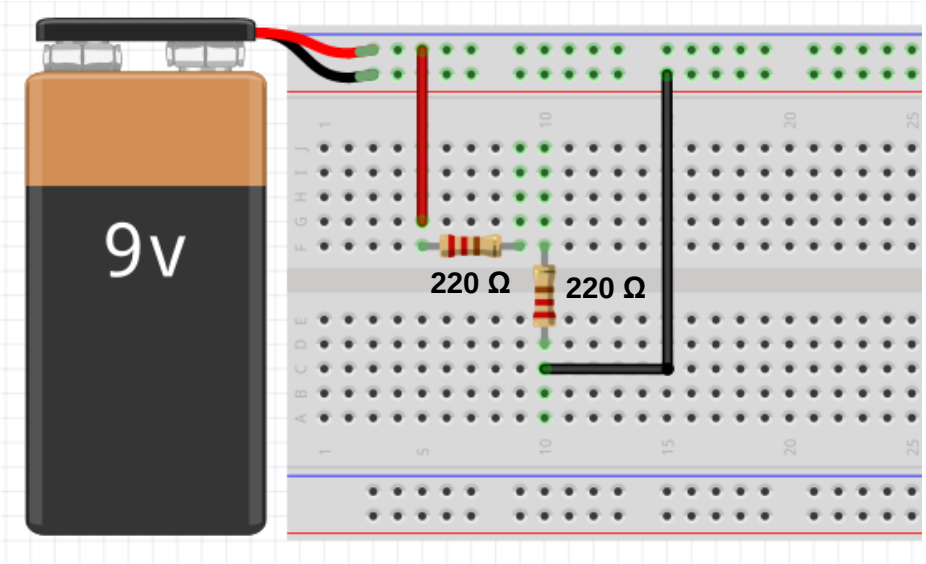
Construct the circuit above using guidelines for proper breadboarding

ACTIVITY - I (SOLUTION)



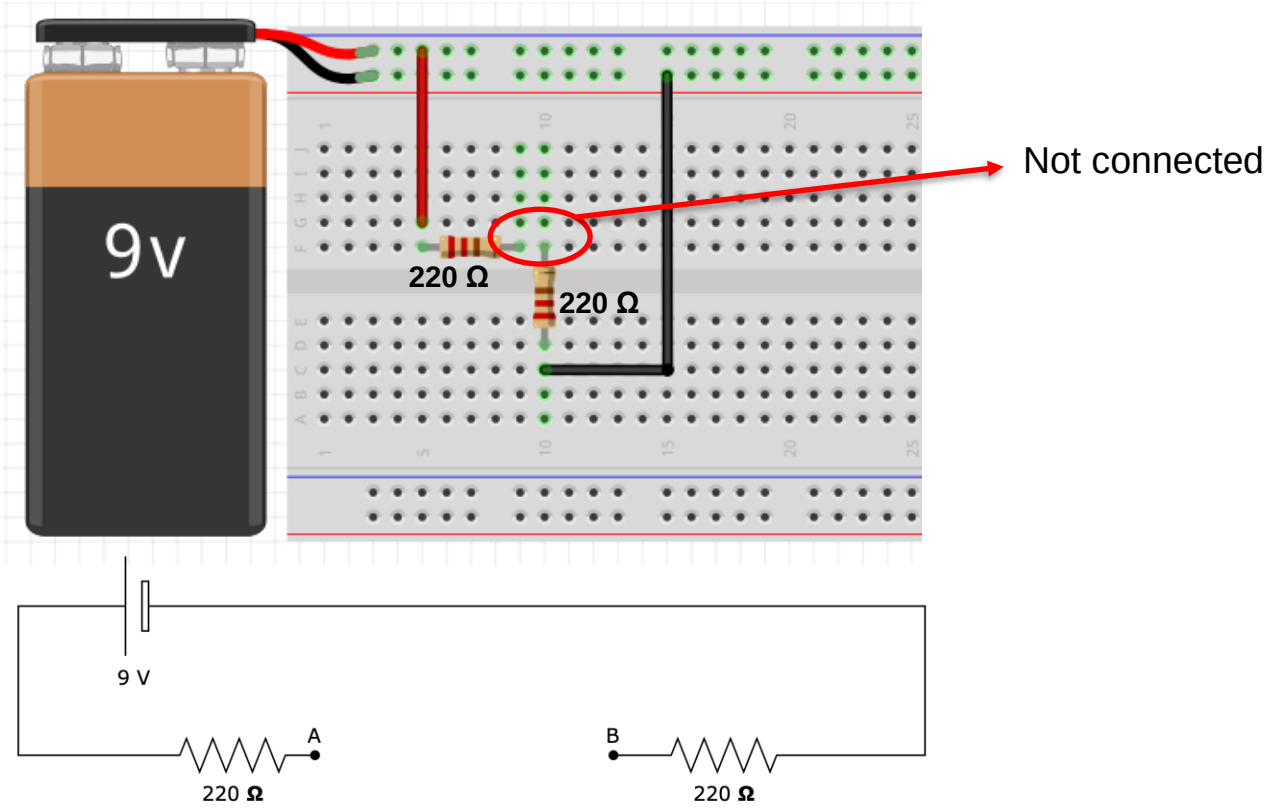


ACTIVITY - II



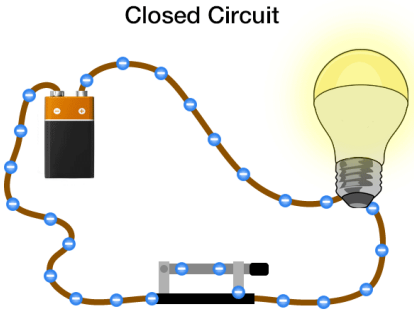
Determine the error in this circuit

ACTIVITY – II (SOLUTION)

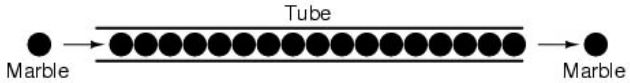


WHAT IS ELECTRICITY

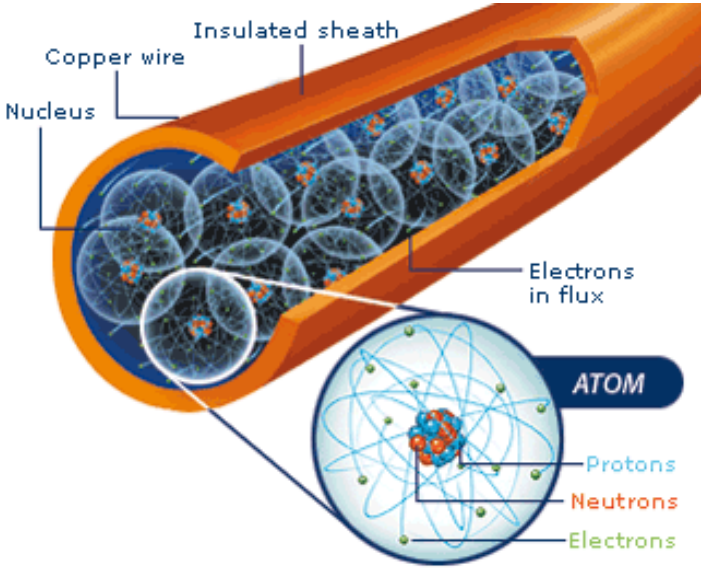
- Everything is made of atoms
- Atom consists of electrons, protons, and neutrons
- Flow of electrons is called electricity



Electric Circuit



Speed of electricity (learn more)



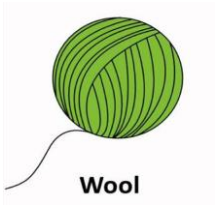
Electrons in a copper wire (Not to scale)

What materials allow electrons to flow?

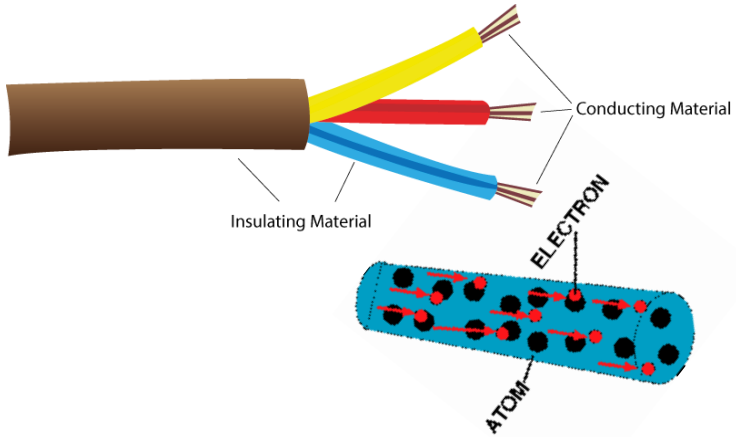
CONDUCTORS AND INSULATORS

Insulators: Some materials have strong attraction forces and refuse to lose electrons, these are called insulators (air, glass, rubber, most plastics)

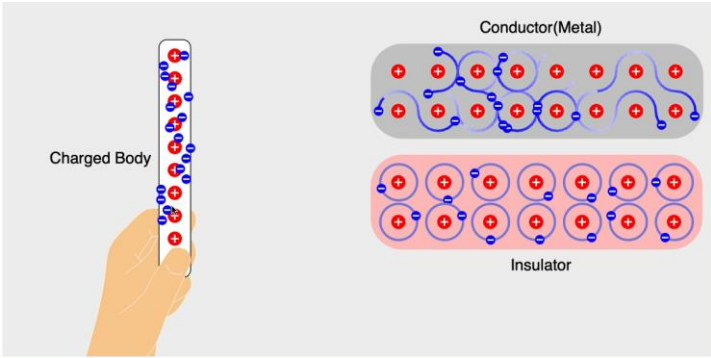
Conductors: Some materials have weak attractions and allow electrons to be lost, these are called conductors (copper, silver, gold, aluminum)



Insulators



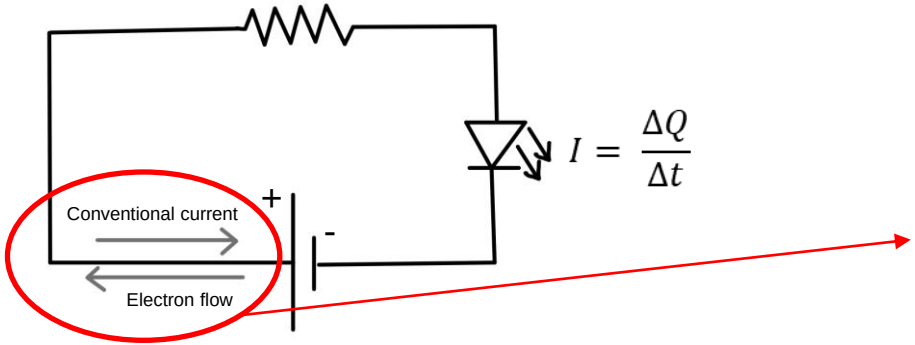
Conductors

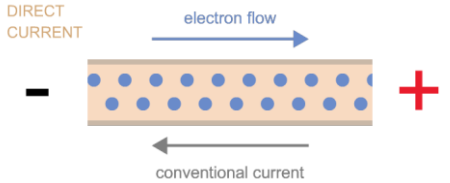


Concept of free electrons→ (Try Yourself)

What is the relationship between electrons and electricity?

ELECTRIC CURRENT





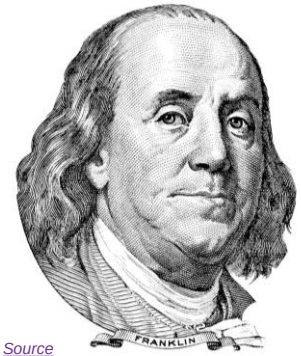
Electron flow v/s coventional current

- Electric current is the flow of charge
- ΔQ is the amount of charge passing through a conductor at any location during some interval of time ΔT
- SI units of current: Amperes (A) 1A = 1 Coulomb/second
- 1.602×10^{19} electrons/sec = 1A current
- Charge carriers are the electrons which flow out of the (-) terminal of the battery and into the (+) terminal

What is the actual direction of current?

CURRENT DIRECTION: CONVENTIONAL

In the **1700s**, **Benjamin Franklin** considered electricity analogous to an **invisible fluid**



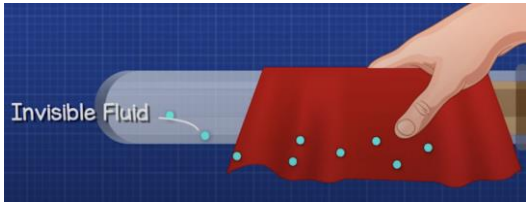
Source

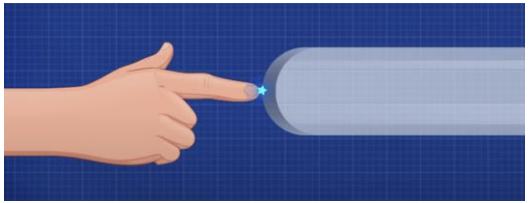
Experiment:

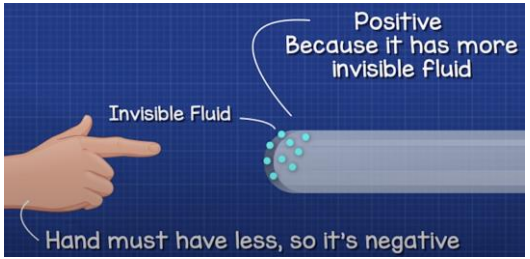
- Rubs glass rod with silk cloth
- Human hand touches the glass rod, observes a spark (now known as static electricity)

Conclusion:

- Assumed that **current** flows from **positive** (glass rod) **to negative** side (hand)
- Similar to how water flows from high level to low level







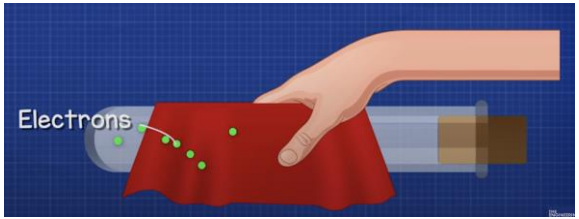
Source

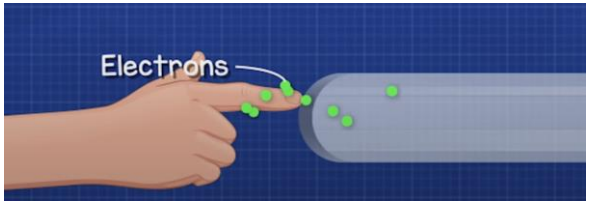
What is the actual direction of current?

CURRENT DIRECTION: ELECTRON FLOW

In reality:

- Silk cloth removes the electrons from the glass rod
- Human hand provides electrons to the glass rod
- The **electrons** flow from **negative** to **positive** side, i.e., the human hand is negatively charge and the glass rod is positively charged
- Opposite of what was assumed by Benjamin Franklin





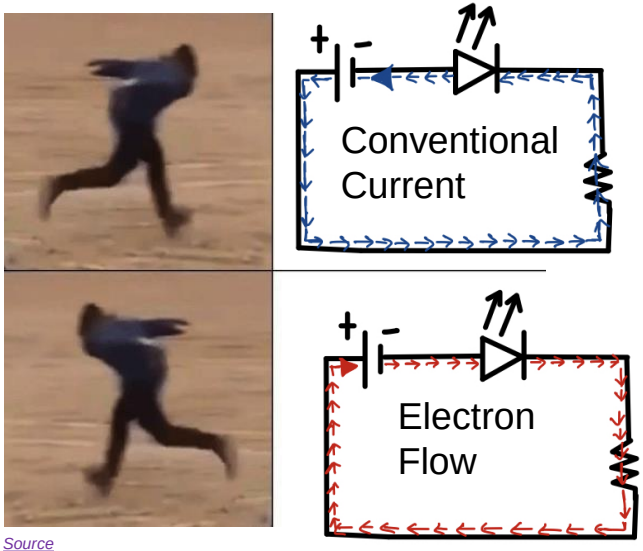
Source

Source

But '**Electron**' was only proven to exist by **Joseph Thomson** in **1897**

What causes these electrons to move?

CURRENT DIRECTION: CONCLUSION



Source

Ideally:

Source

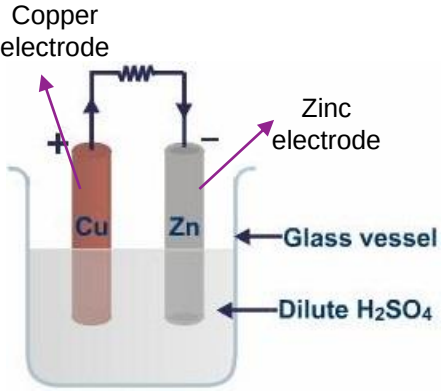
It should be known that electrons being the charge carriers, the actual current direction is the that of electron flow

However, most textbooks and equations in the electrical domain assume **conventional current direction**

What causes these electrons to move?

BATTERIES

- A battery produces electricity by **transforming chemical energy into electrical energy**, using various metal electrodes immersed in an electrolytic solution
- Batteries are the source of potential difference $\Delta V = V_a - V_b$ **and measured in SI units of volts (V)**



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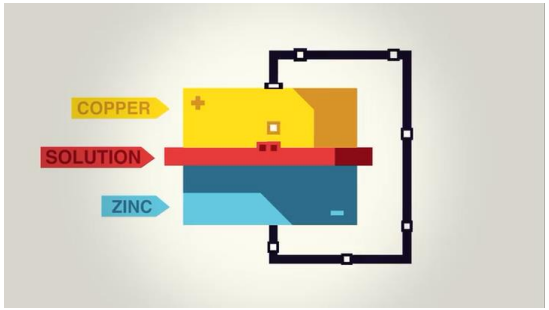


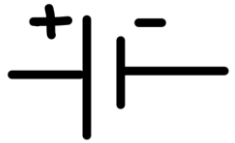
How batteries work

Source

Source

Alessandro Volta - inventor of electric cell

Circuit symbol of battery:

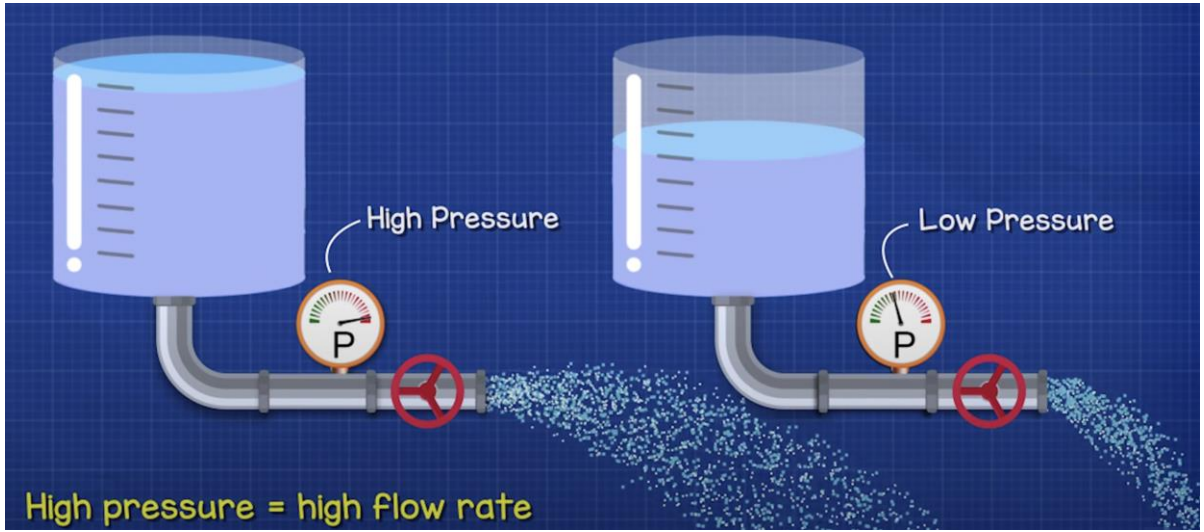


Is there a simpler way to understand current and voltage?

VOLTAGE AND CURRENT

Voltage → Pressure

Current → flow of water



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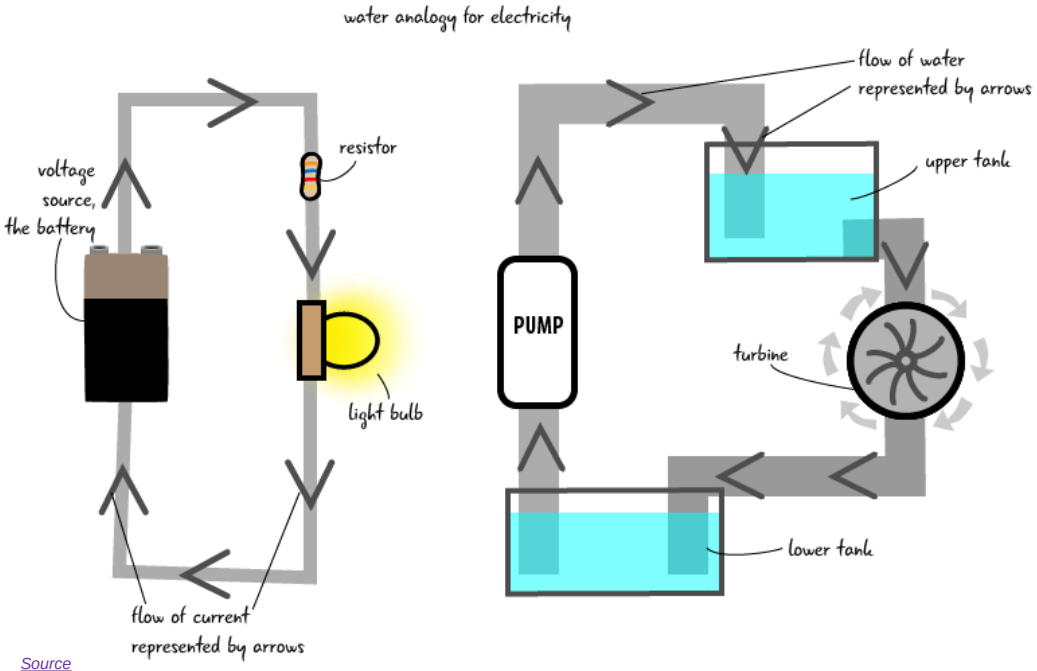
What kind of connections do we have for flow of electricity?

VOLTAGE AND CURRENT



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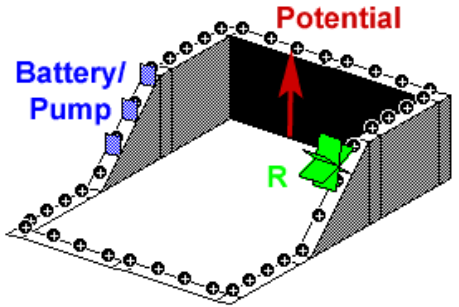
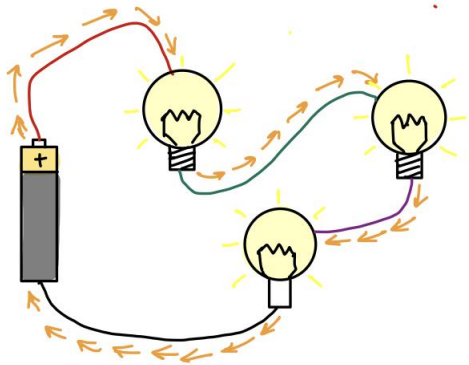
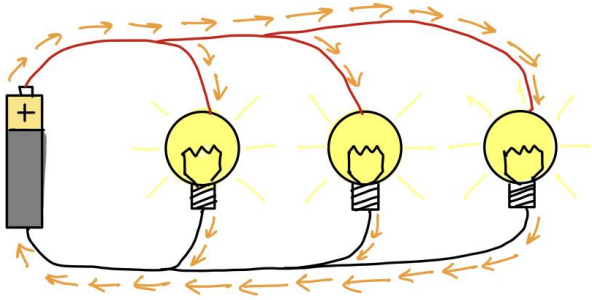


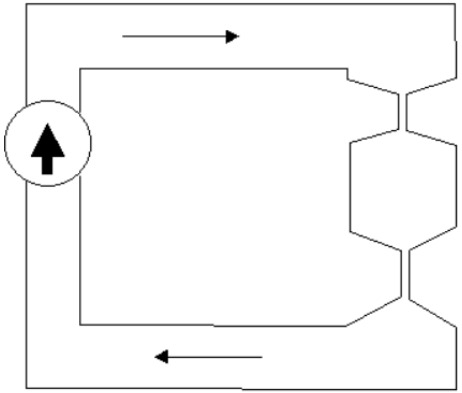
Water analogy

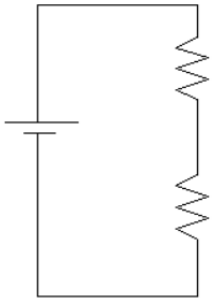
What kind of connections do we have for flow of electricity?

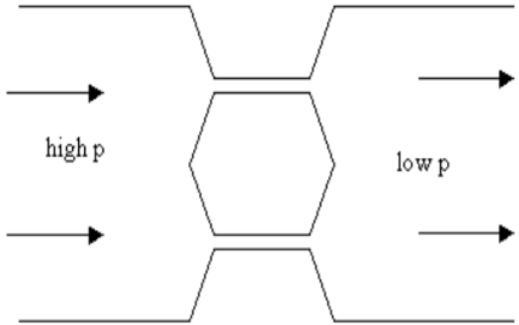
SERIES VS. PARALLEL CIRCUITS

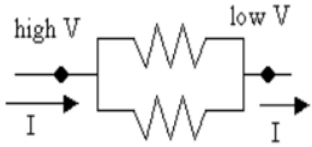








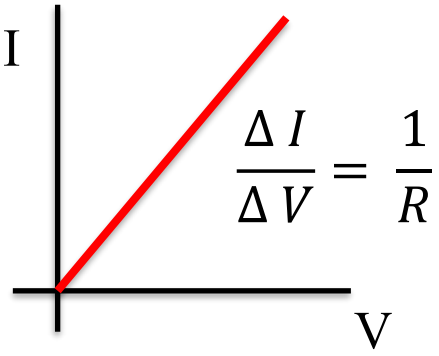




What about components other than batteries and bulbs?

RESISTANCE

In 1850, Georg Simon Ohm determines that flow of electric current through a conductor experiences a certain amount of resistance



The resistance expressed in ohms, named after George ohm, is a measure of how much. A resistor resists the flow of electricity

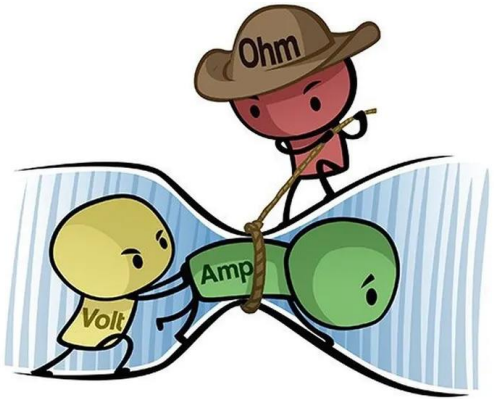
This impediment to current flow is due to electron collisions resulting in behavior called resistance

$$I \propto V \rightarrow I = G \times V \rightarrow I = \frac{V}{R} \rightarrow R = \frac{V}{i} \rightarrow V = I \times R$$

$V = I \times R$ is called **Ohm's law**

R is the resistance and G is the conductance in the circuit

SI unit: Ohms, 1 Ω = 1 volt /ampere



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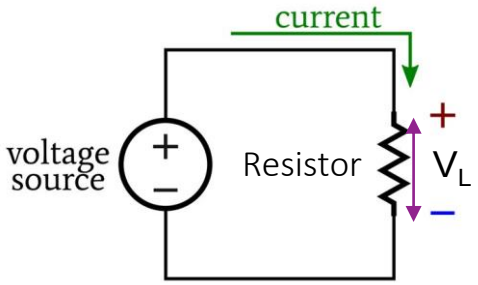
RESISTORS

- All electrical components which represent a **load** in a circuit can be modeled as an **impedance** (a general form of resistance)

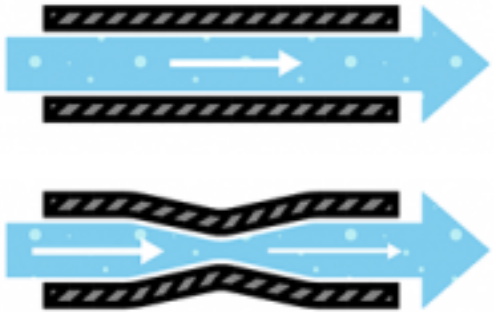


Source

- A *resistor* is a device that offers a specified amount of resistance and is used to **control current** in an electronic circuit

Source

Less resistance

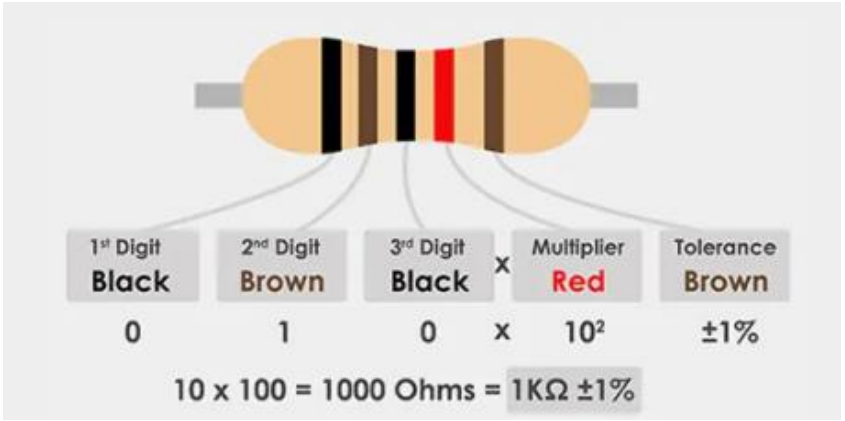


More resistance

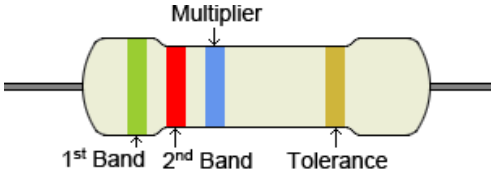
Source

RESISTOR COLOR CODING

- Resistors are color coded by various bands to indicate the resistance value.
- The number of bands are usually 4 or 5.
- The resistance value is calculated as shown



Source



Color	1st, 2nd Band Significant Figures	Multiplier	Tolerance
Black	0	× 1	
Brown	1	× 10	±1% (F)
Red	2	× 100	±2% (G)
Orange	3	× 1K	±0.05% (W)
Yellow	4	× 10K	±0.02% (P)
Green	5	× 100K	±0.5% (D)
Blue	6	× 1M	±0.25% (C)
Violet	7	× 10M	±0.1% (B)
Grey	8	× 100M	±0.01% (L)
White	9	× 1G	
Gold		× 0.1	±5% (J)
Silver		× 0.01	±10% (K)

Source

MULTIMETER

Video

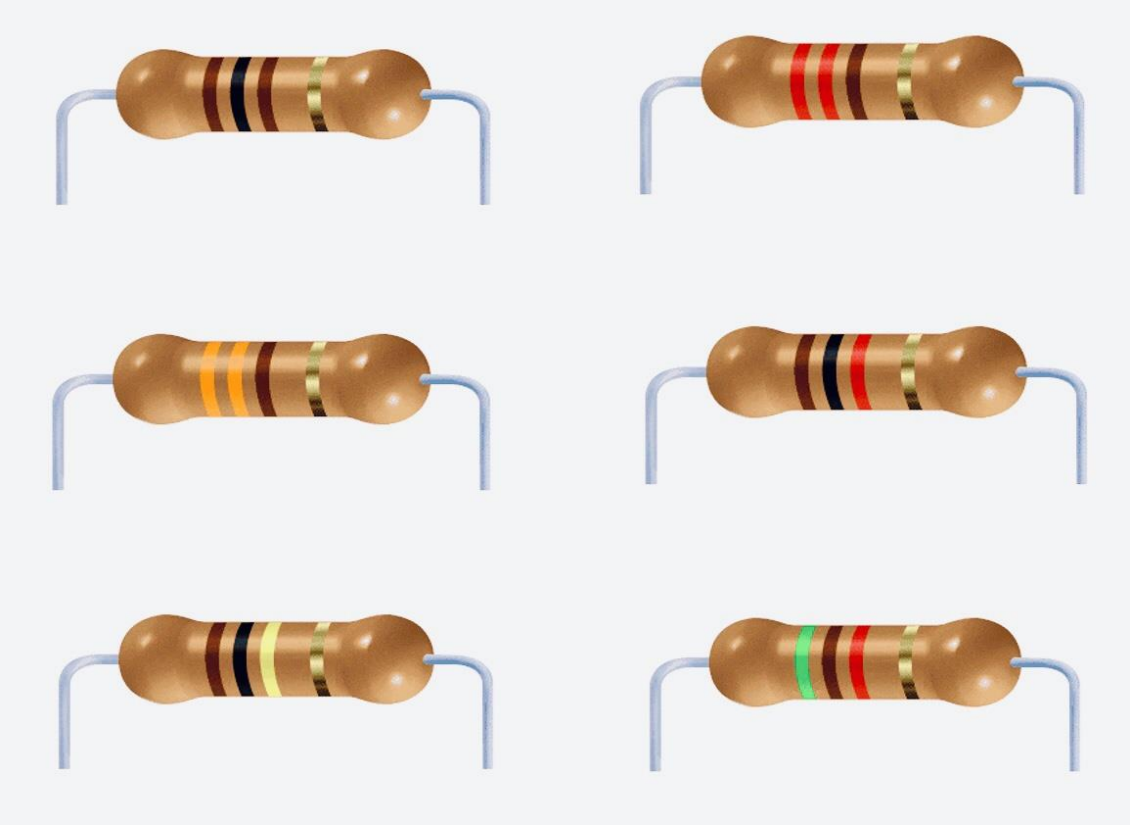
ACTIVITY III

- Calculate resistor value based on color coding
- Check using multimeter

	1st Digit	2nd Digit	Multiplier	Tolerance
Black	0	0	x 1	
Brown	1	1	x10	±1%
Red	2	2	$x10^2$	±2%
Orange	3	3	$x10^3$	±3%
Yellow	4	4	$x10^4$	±4%
Green	5	5	$x10^5$	±0.5%
Blue	6	6	$x10^6$	±0.25%
Violet	7	7	$x10^7$	±0.1%
Grey	8	8	$x10^8$	±0.05%
White	9	9	$x10^9$	
Gold			$x10^{-1}$	±5%
Silver			$x10^{-2}$	±10%

Source

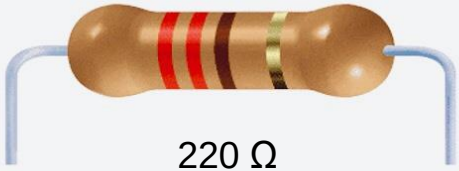
ACTIVITY III

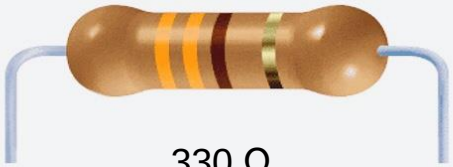


- Calculate resistor values based on color coding
- Check values with multimeter readings

ACTIVITY III (SOLUTION)


100 Ω


220 Ω


330 Ω


1 kΩ


100 Ω

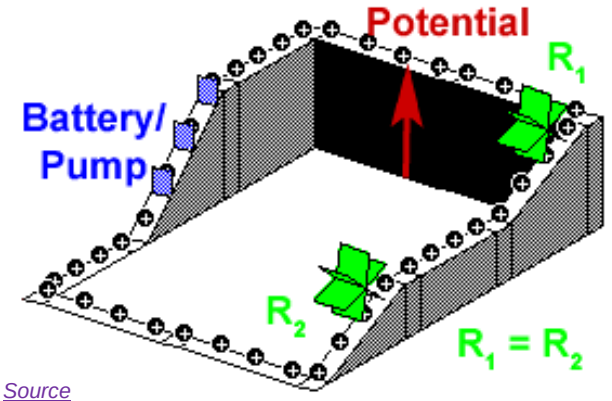

5.1 kΩ

RESISTORS IN SERIES

- When connected in series, the total resistance (R_T) is equal to:

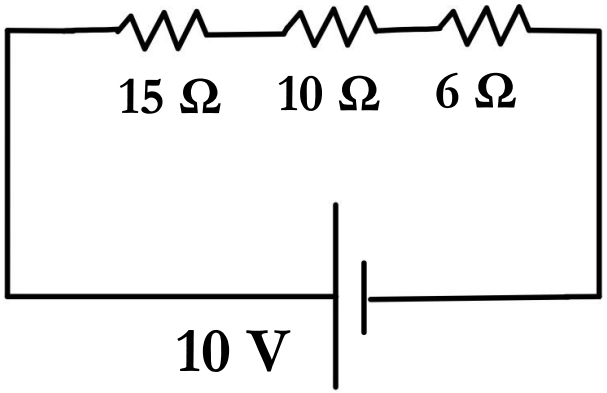
$$R_T = R_1 + R_2 + R_3 + \ldots$$

- The total resistance is always larger than any individual resistance.



Source

RESISTORS IN SERIES



Example :

R_T = 15+10+6 = **31 Ω**

Current = $I = V/R_T$ = 10/31 = **0.32 A**

RESISTORS IN PARALLEL

- When connected in parallel, the total conductance (G_T) is found using

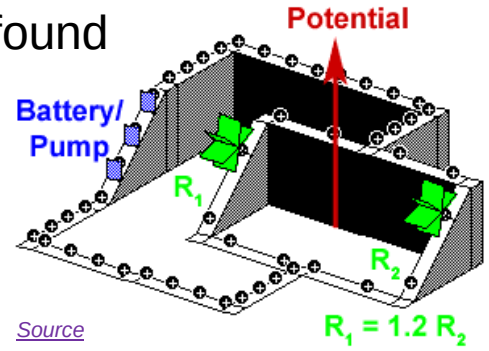
$$G_T = G_1 + G_2 + G_3 + \ldots$$

- and the total resistance is calculated using

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

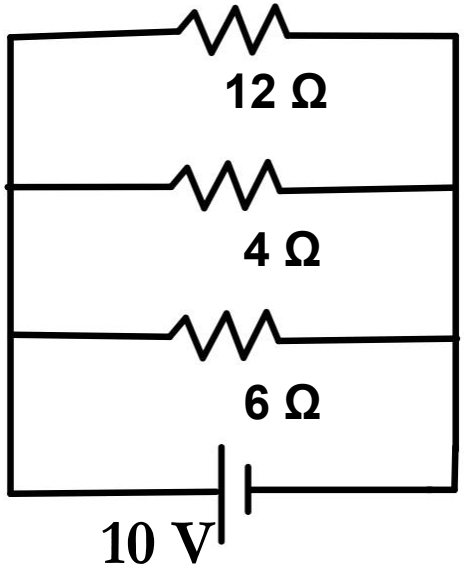
- Due to the reciprocal relationship, the total resistance is always smaller than any individual resistance

- Since there is more than one possible path, the current divides itself according to the resistance of each path



Source

RESISTORS IN PARALLEL



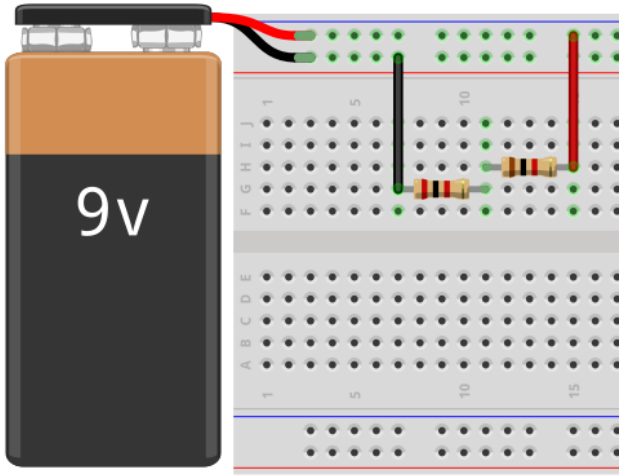
Example :

$$\frac{1}{R_T} = \frac{1}{12} + \frac{1}{4} + \frac{1}{6} \quad <= R_T = \mathbf{2\ \Omega}$$

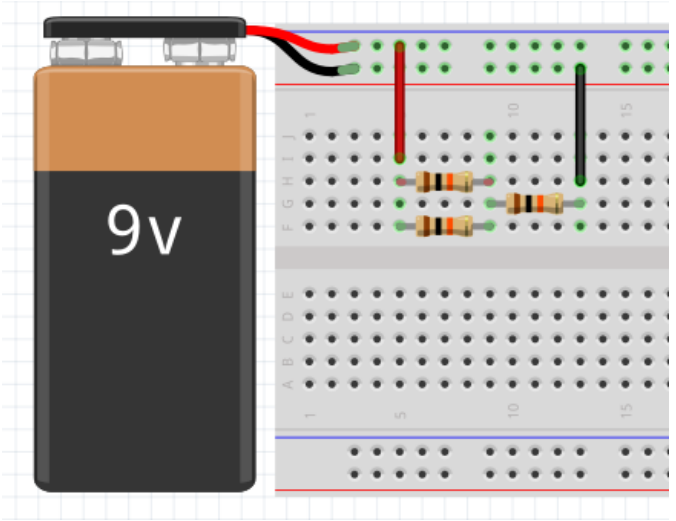
smallest resistor = more current passes
largest resistor = least current passes

ACTIVITY - IV

(I)



(II)



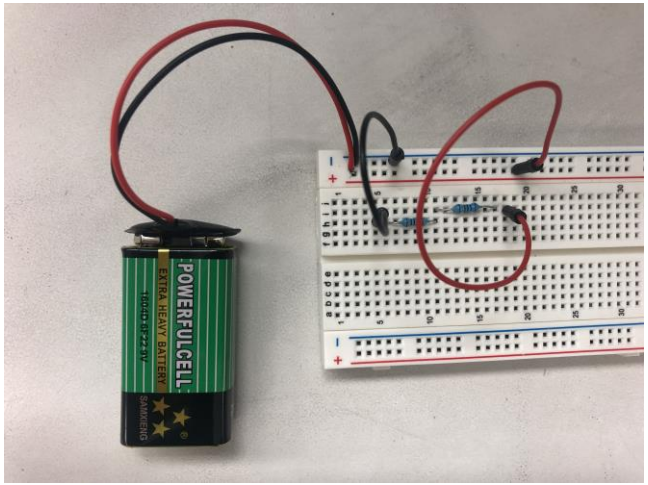
Determine the connection type and calculate total resistance for each figure

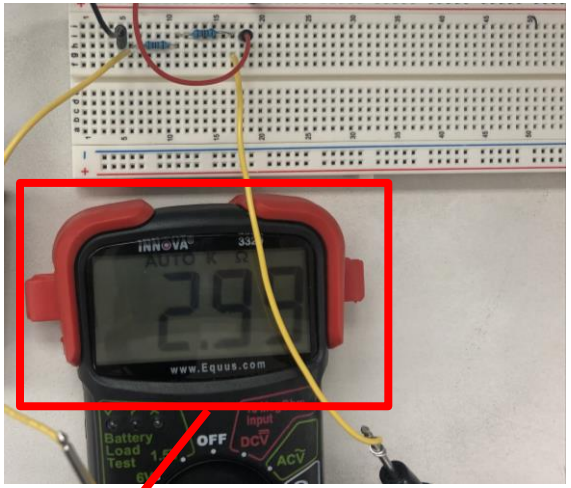
ACTIVITY – IV (SOLUTION)

(I)

Series Connection

R_T = 2000 + 1000 = **3 kΩ**





2.99 kΩ

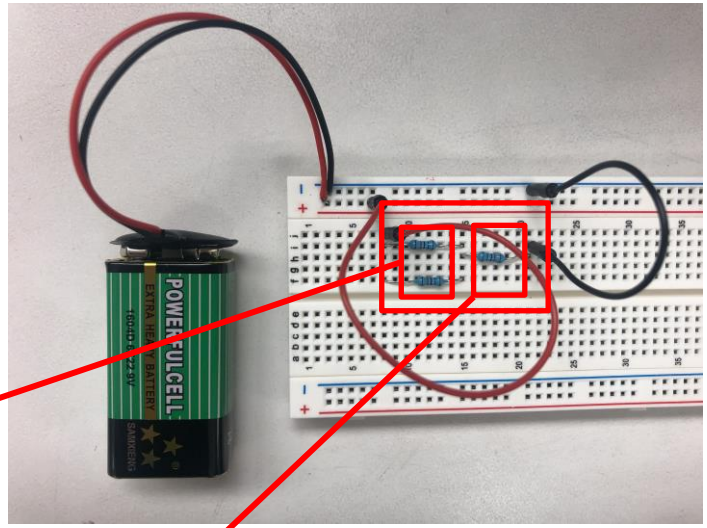
ACTIVITY – IV (SOLUTION)

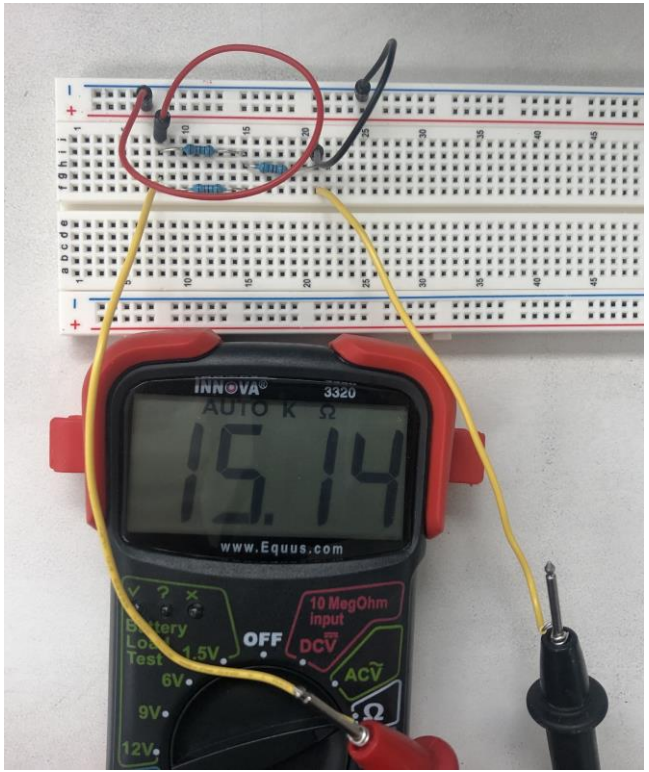
(II)

Parallel Connection

$$\frac{1}{R_P} = \frac{1}{10000} + \frac{1}{10000}$$

$$R_P = 5000\ \Omega$$

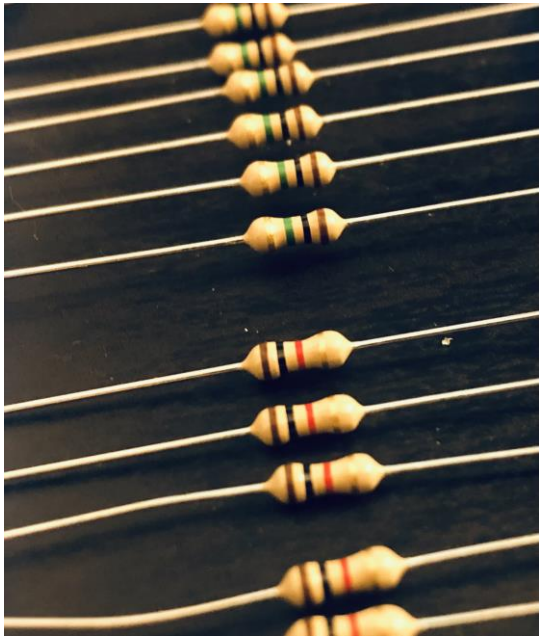




Series Connection

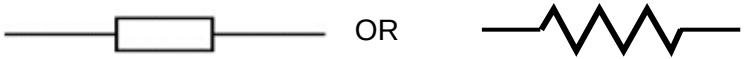
R_T = 5000 + 10000 = **15 kΩ**

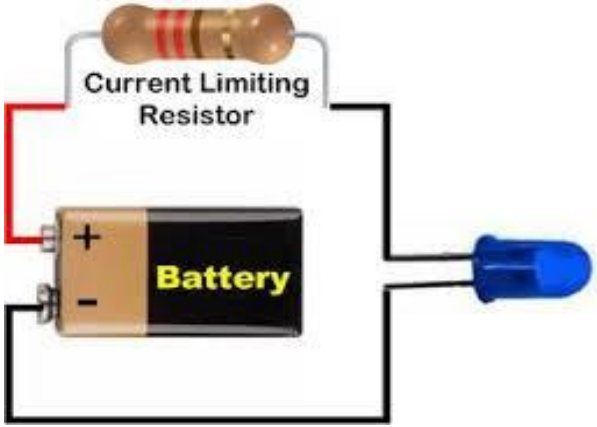
RESISTOR



Source

Circuit symbol for a resistor (fixed resistance)





A **resistor** is a **passive** component that **limits the electrical current** flowing in a circuit

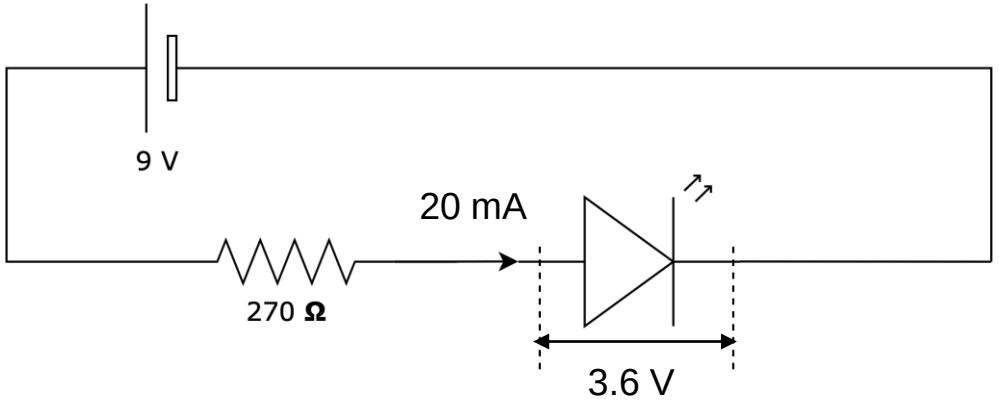
CHOOSING THE RESISTOR

Supply Voltage = V1 = 9V

LED Voltage = V2 = 3.6 V

LED current = 20 mA = 0.02 A

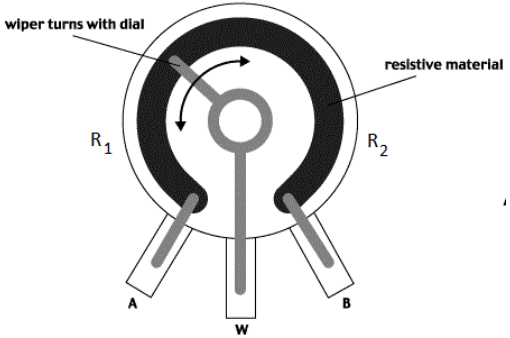
V = I x R
→ R = (V2 – V1) / I
→ R = (9V – 3.6V) / 0.02
→ R = 270 Ω



Any resistor with a value above 270Ω should work

VARIABLE RESISTOR

Source



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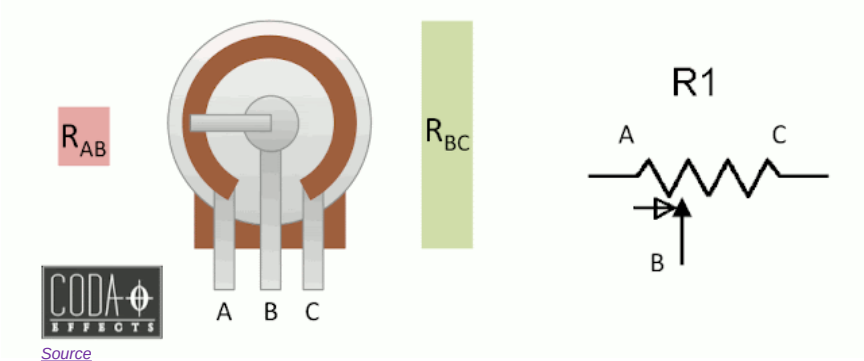
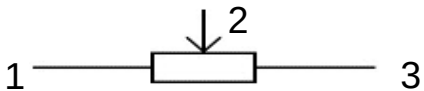
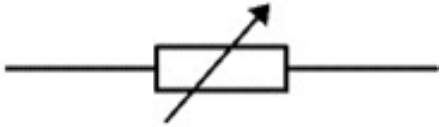


Source

Circuit symbol:



OR



OR

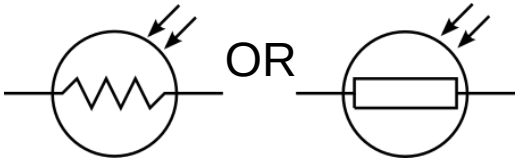
Source

Variable resistors consist of a **resistance track** with connections at both ends and a **wiper** which moves along the track as you turn the spindle.

LIGHT DEPENDENT RESISTOR (LDR)

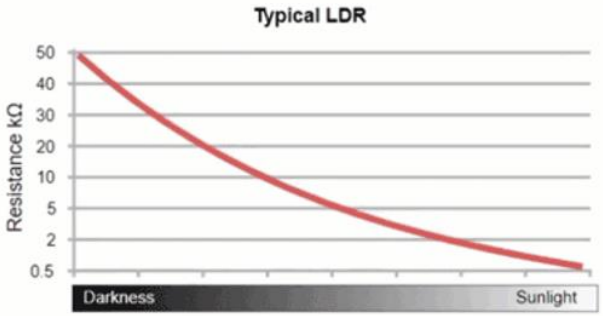
Source

Circuit symbol:



Source

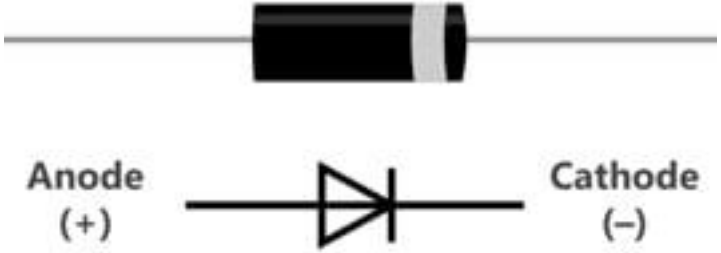
Source



- An LDR is an **input transducer** (sensor) which converts brightness (light) to resistance
- The resistance decreases as the brightness of light falling on the LDR increases

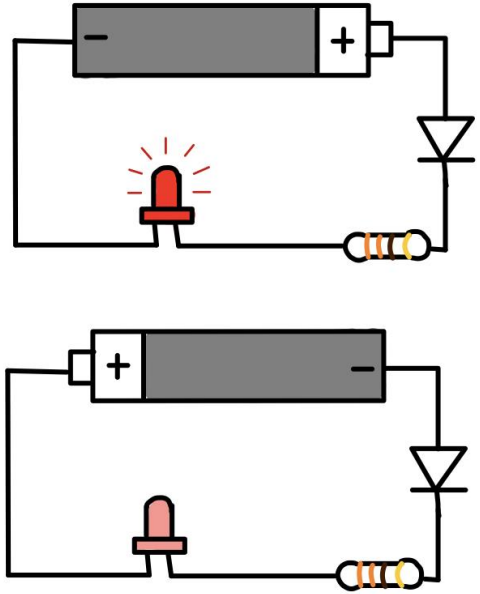
DIODE

Direction of current flow →



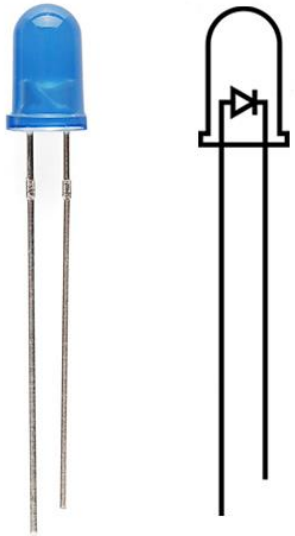
Source

Source

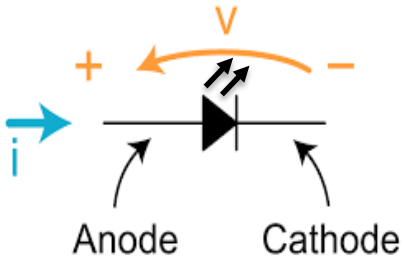


A **diode** is a two-terminal electronic component that conducts electric **current in only one direction**

LIGHT-EMITTING DIODE (LED)



Source



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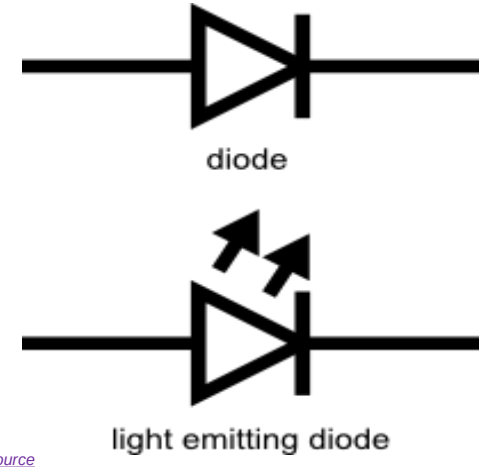
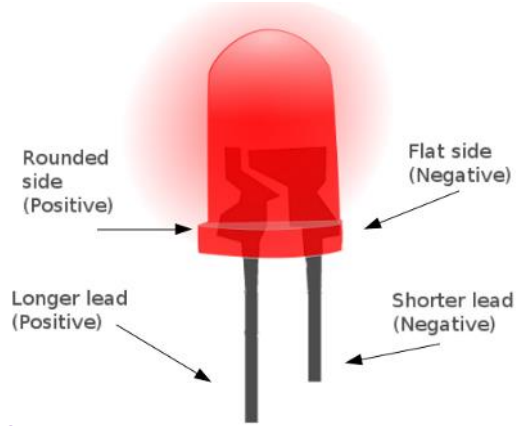


Source

Circuit Symbol

A Light emitting diode is simply **a diode that lights up** when current flows through one direction

LED POLARITY



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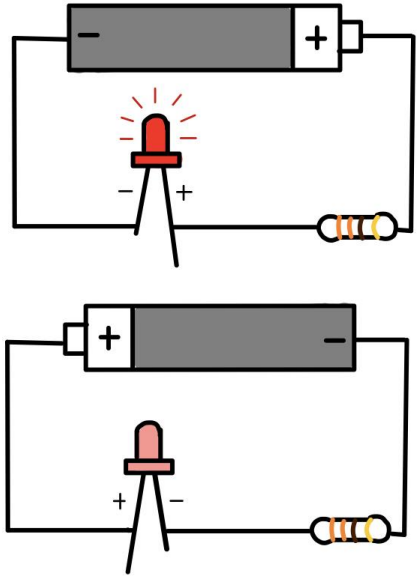
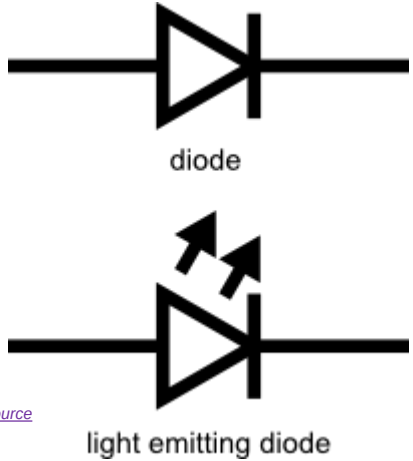


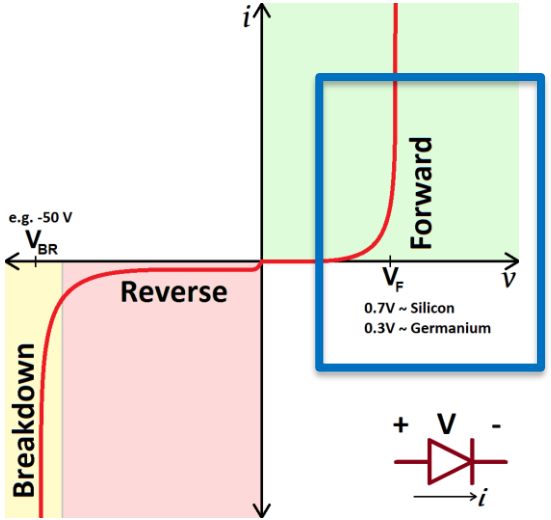


Source

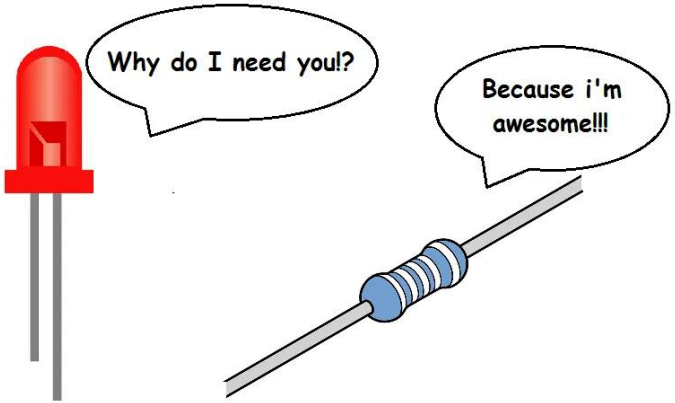
A Light emitting diode is simply **a diode that lights up** when current flows through one direction

DIODES AND LEDS

Never connect the LED or Diode circuit without resistor - Very dangerous – such a connection will burn the LED and other possible components in the circuit



Source



Source

DIODES AND LEDS

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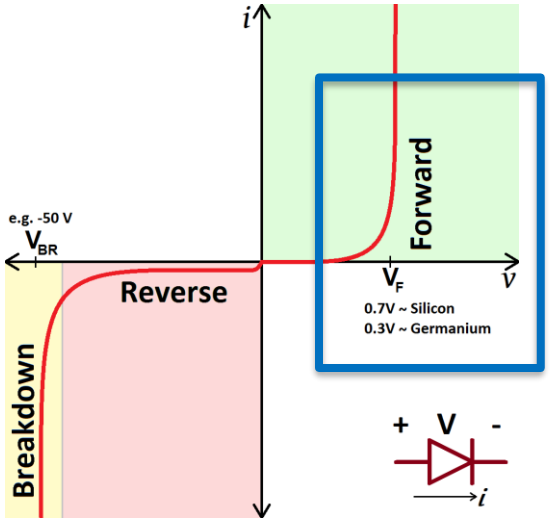

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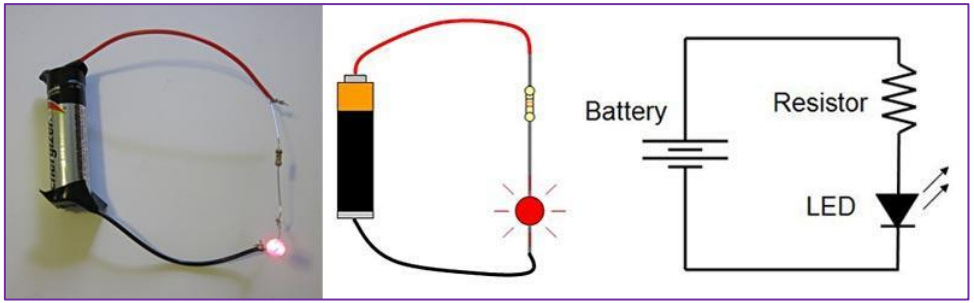
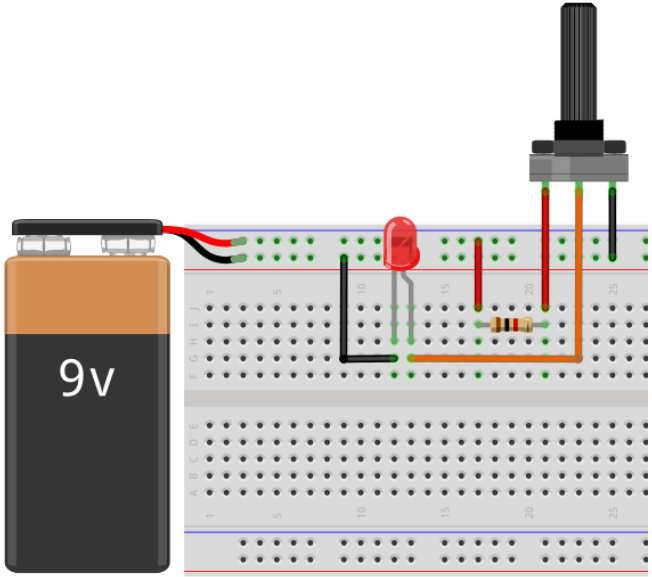


Source

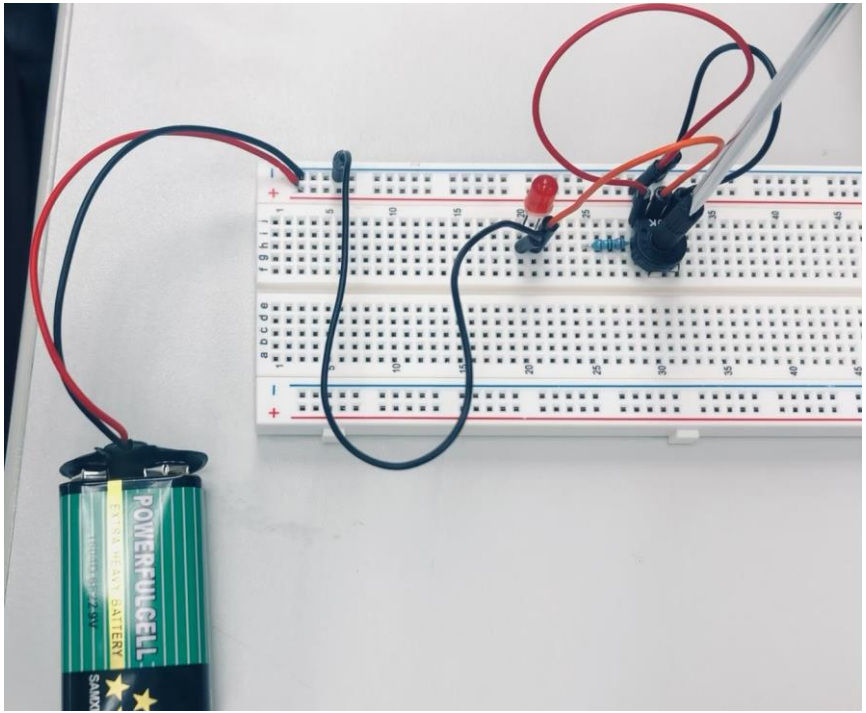
SAFE WAY TO USE LED

ACTIVITY - V



Construct this circuit and check if brightness of LED changes with variable resistor (10 kΩ)

ACTIVITY – V (SOLUTION)

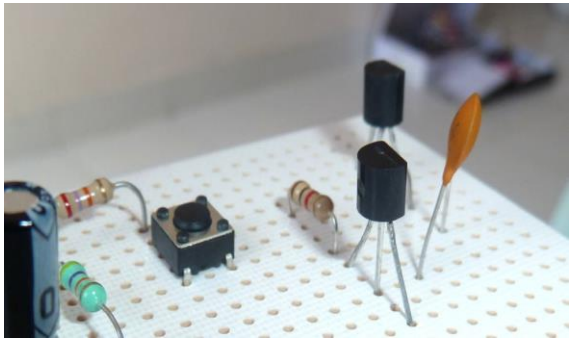


Video

Using variable resistor to control LED brightness

TRANSISTORS

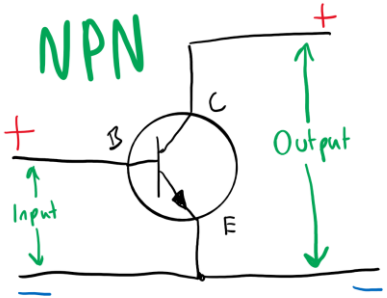
- A transistor is like an **electronic switch**
- It can turn a current on and off
- A **Bipolar Junction Transistor** (BJT) has three pins: **Base (b), collector (c), and emitter (e)**
- BJT comes in two versions: **NPN and PNP**

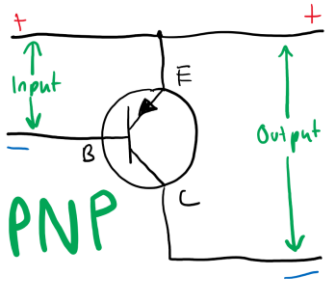


Source

1. Emitter
2. Base
3. Collector

Source



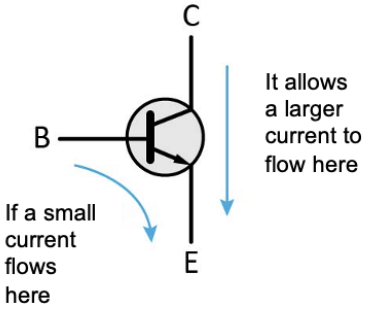


Source

Fun fact: *The 3rd Generation Intel® Core™ processor — quad core, contains* ***1.48 billion*** *transistors*

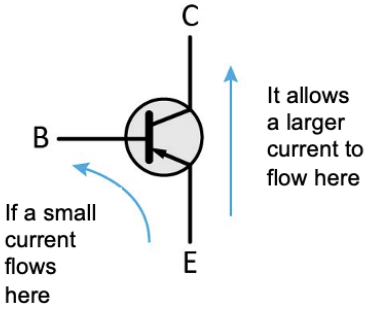
HOW TRANSISTORS WORK

- The transistor works because of the way p- and n-type semiconducting materials are **sandwiched**
- A current flowing from the base to the emitter “opens” the flow of current from the collector to the emitter

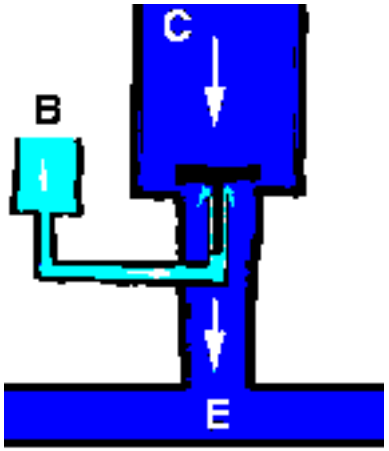


NPN Transistor

Source

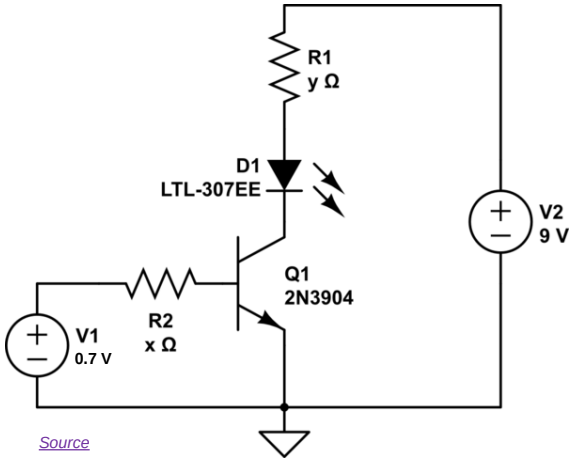


PNP Transistor



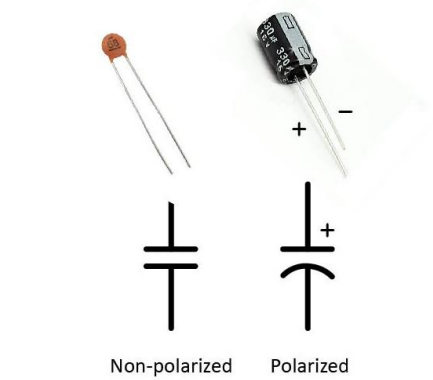
Source

Water analogy



Source

CAPACITOR



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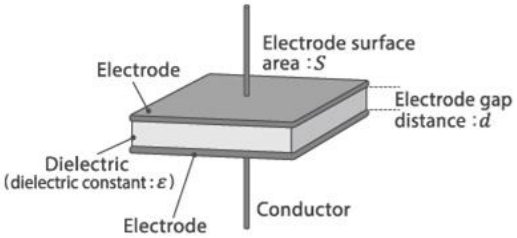
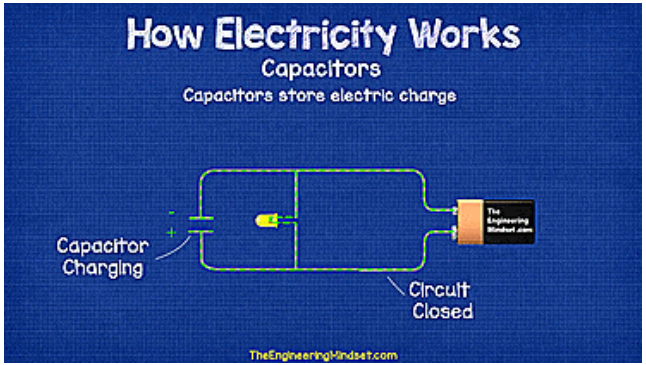


Source

Capacitor in action

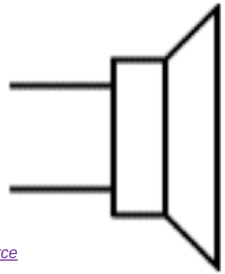


- A capacitor is a **passive** electronic component **that stores energy** in the form of an electrostatic field
- The capacitance is directly proportional to the **surface areas** of the plates and is inversely proportional to the **separation** between the plates
- Capacitance also depends on the **dielectric constant** of the substance separating the plates

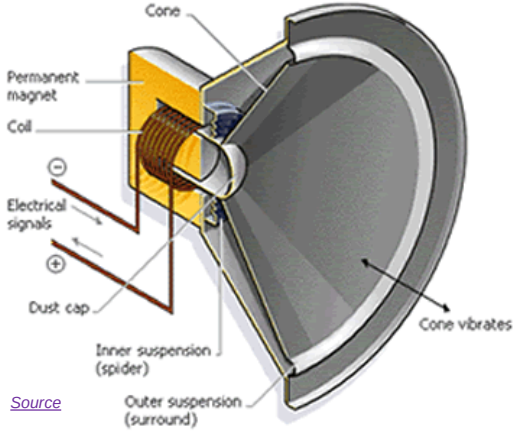
SPEAKER

Source

Circuit symbol:

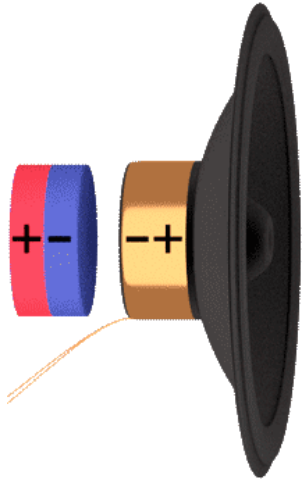


Source



Source

Speaker working



- A **speaker** is an electroacoustic transducer that converts an **electrical signal into sound**
- The speaker **moves** in accordance with the variations of an **electrical signal** and causes sound waves to propagate through a medium such as air or water

MECHANICAL SWITCHES

SWITCHES

SPDT

Source

DPDT

Source

DPST

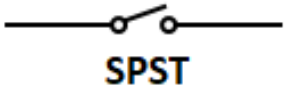
Source

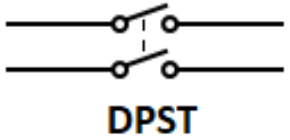
SPST

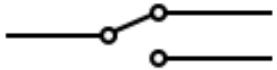
Source

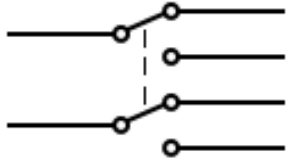
Source

Note: S – Single, D– Double, P – Pole, T - Throw





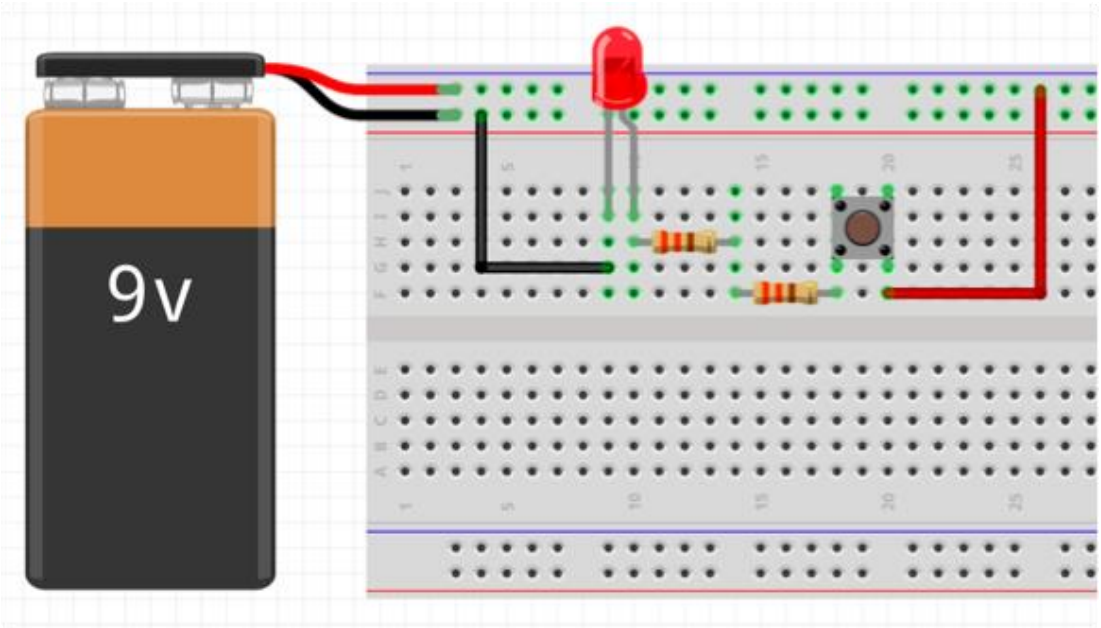




Source

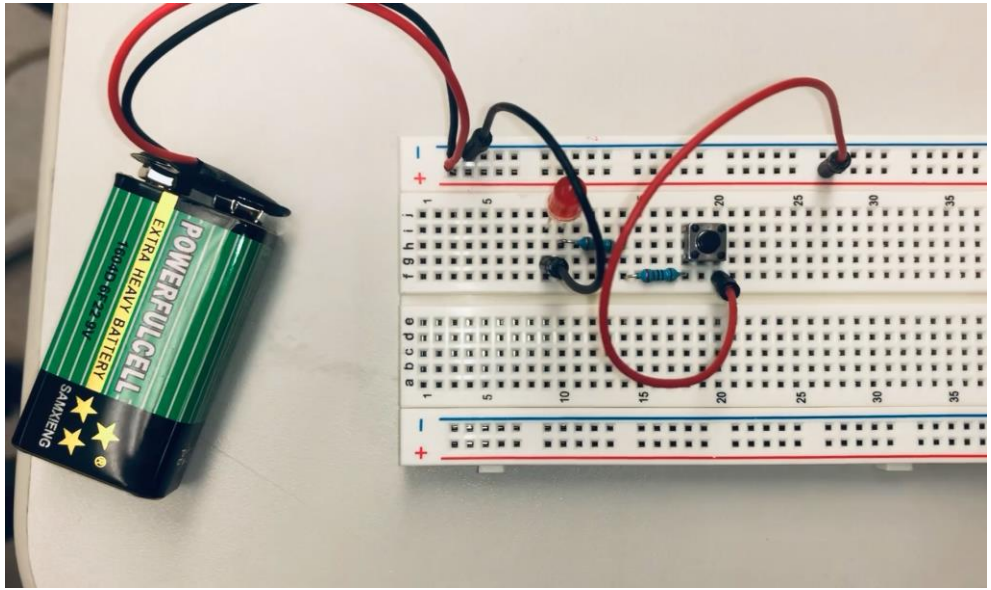
In electrical engineering, a switch is an electrical component that can **"make" or "break" an electrical circuit**, interrupting the **current** or diverting it from one conductor to another

ACTIVITY - VI



Construct circuit such that switch can turn on and off LED

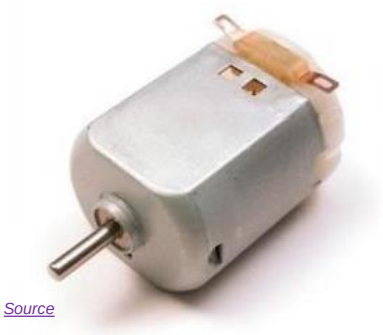
ACTIVITY - VI (SOLUTION)



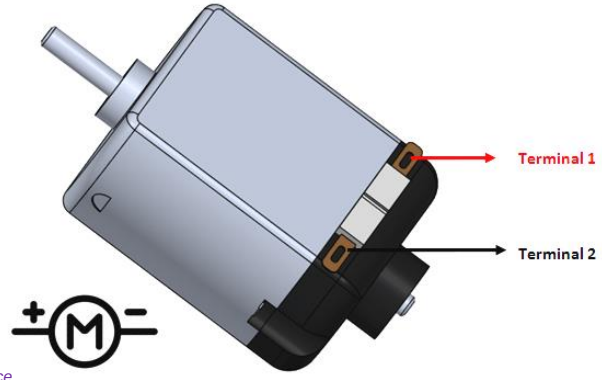
Video

Turning an LED on/off using a mechanical switch

MOTOR

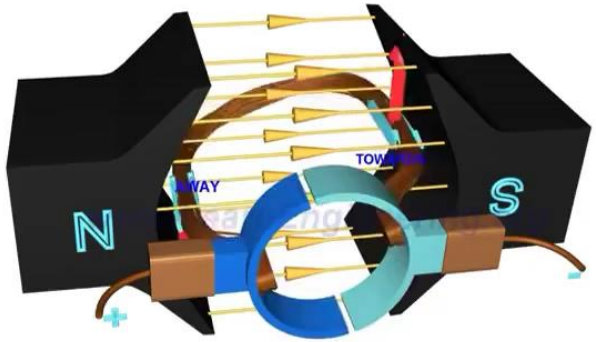


Source



Source

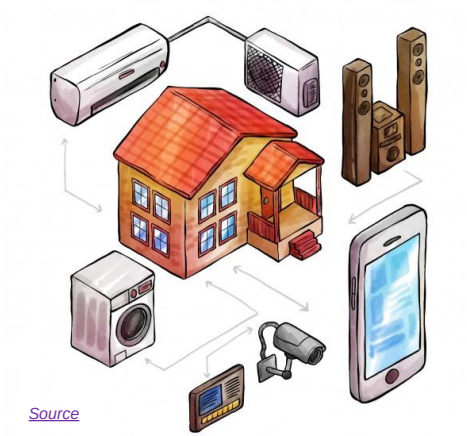
DC motor working:



- Motors are often used to turn wheels, gears, cams or pulleys
- Motors have **two terminals** that connect to a battery
- The **direction** of the turning depends on the way the battery wires are connected to the terminals

WHAT DIGITAL ELECTRONICS DO YOU USE?

- Computer
- CD & DVD players
- iPod
- Cell phone
- HDTV
- Digital cameras



Source

Source

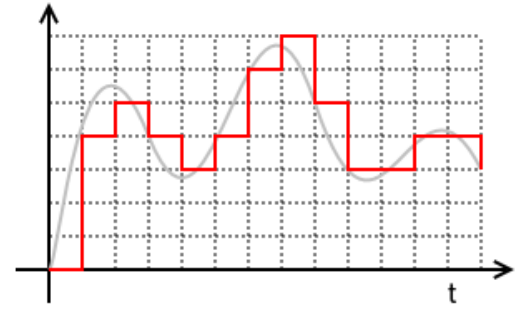
Source

Source

Source

WHAT IS DIGITAL ELECTRONICS?

- Most signals in real life are not digital. For example, sound is an **analog** signal
- On a **CD**, **digital sound** is encoded as 44.1 kHz, 16 bit audio
  - The original wave is **'sliced'** 44,100 times a second – and an average amplitude level is applied to each sample
  - 16 bit means that a total of 65,536 different values can be assigned, or **quantized** to each sample
- DVD-Audio can be 96 or 192 kHz and up to 24 bits resolution
- To control things like switches we need **true or false decisions**, which is basically digital electronics



Source

Source

NYU GEORGE BOOLE – Father of Boolean Algebra

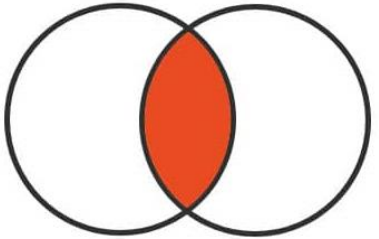
- George Boole, a British mathematician (1815-1864) proposed logic and math are equivalent

- All math functions can be determined using these 3 primary Boolean logic operators: AND, OR, and NOT

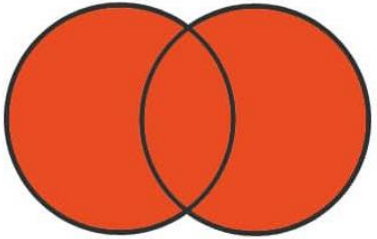
- AND narrows your search,

OR broadens your search, and

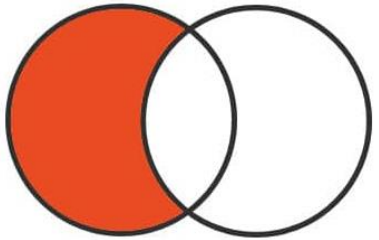
NOT is used to exclude concepts



AND



OR

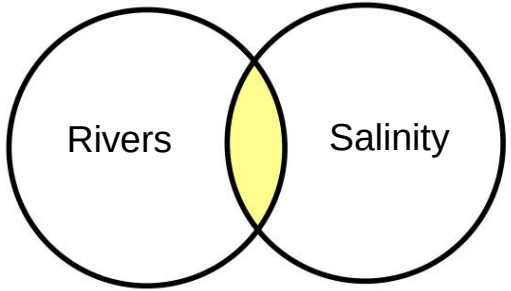


NOT

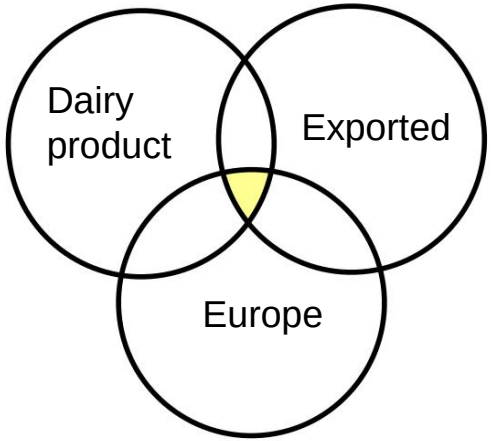
Source

THE AND OPERATOR (INTERSECTION)

River AND Salinity

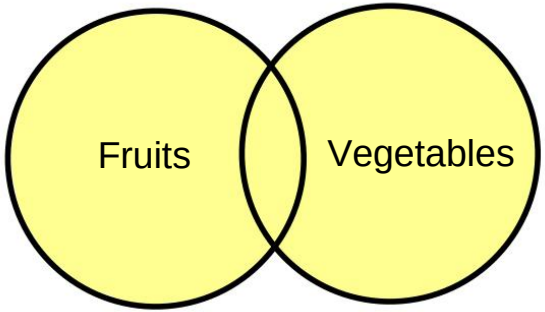


Dairy product AND Exported AND Europe

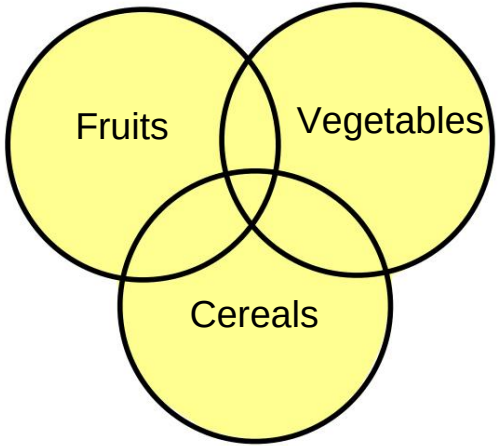


THE OR OPERATOR (EITHER, ANY)

Fruits OR Vegetables



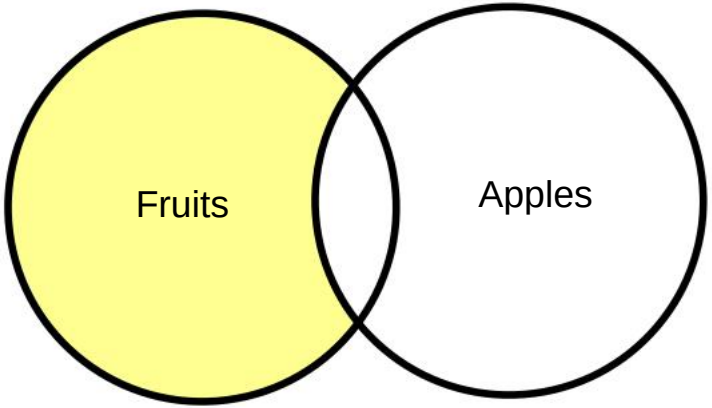
Fruits OR Vegetables OR Cereal



from CSIRO Australia

THE NOT OPERATOR

Fruits NOT Apples



Look at the Boolean Machine https://www.rockwellschrock.com/rbs3k/boolean/

BASIS FOR DIGITAL COMPUTERS

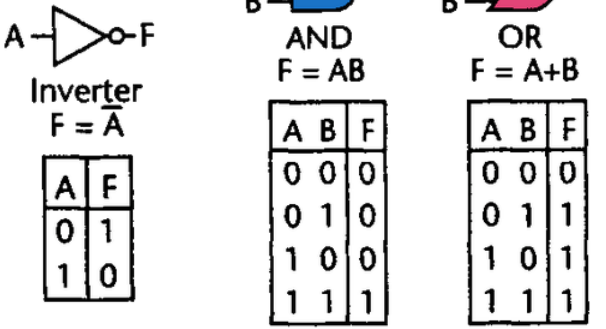
- The **true-false** nature of Boolean logic makes it compatible with binary logic used in digital computers

- Electronic circuits can produce **Boolean logic** operations

- Circuits are called gates
  - **NOT**
  - **AND**
  - **OR**

It's all binary at low-level

Source

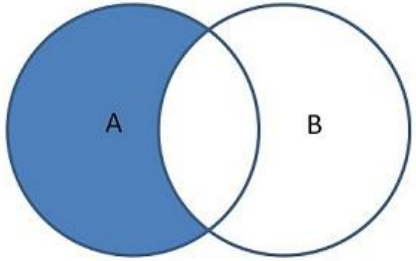


Source

Source

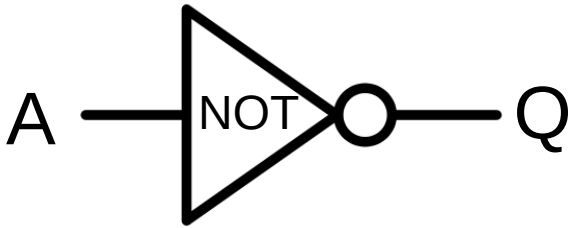
‘NOT’ GATE

- The simplest possible gate is called an "**inverter**," or a NOT gate
- One bit as input produces its **opposite** as output
- The symbol for a NOT gate in circuit diagrams is shown below
- The logic table for the NOT gate shows input and output



Source

A	Q
0V	5V
5V	0V

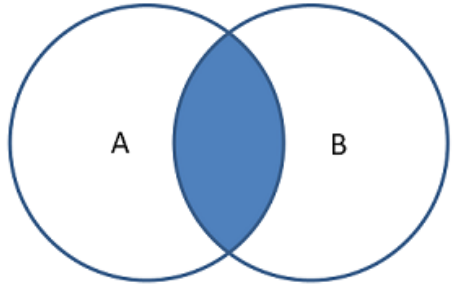


Source

A	Q
0	1
1	0

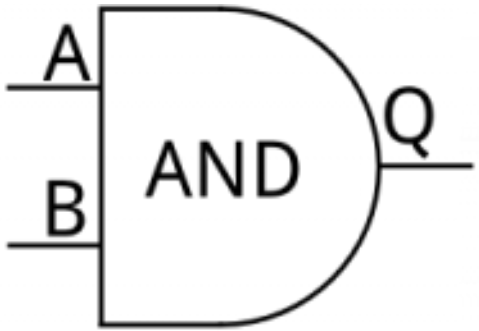
‘AND’ GATE

- The AND gate has the following symbol and logic table
- Two or more input bits produce one output bit
- **Both inputs must be true** (1) for the output to be true
- Otherwise, the output is false (0)



A AND B

Source

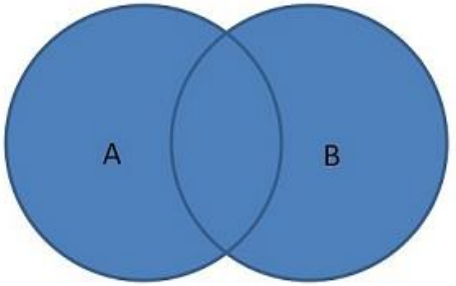


Source

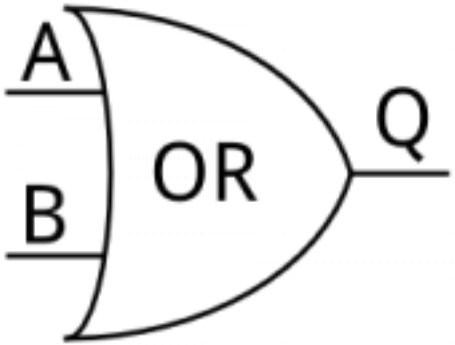
A	B	Q
0	0	0
0	1	0
1	0	0
1	1	1

‘OR’ GATE

- The OR gate has the following symbol and logic table
- Two or more input bits produce one output bit
- Either inputs must be true (1) for the output to be true



Source

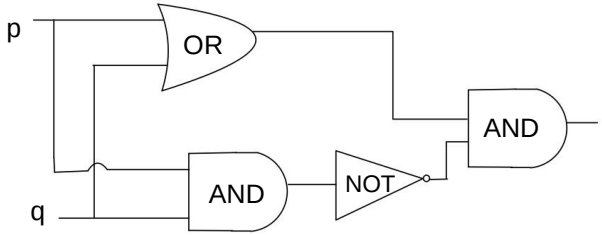


Source

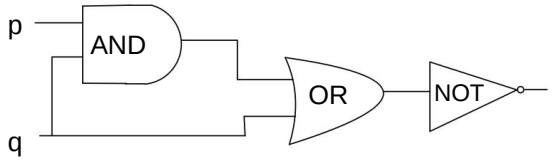
A	B	Q
0	0	0
0	1	1
1	0	1
1	1	1

COMBINE GATES – EXERCISE 1

- Gates can be combined
- The output of one gate can become the input of another
- **Try to determine the logic table for these circuits**

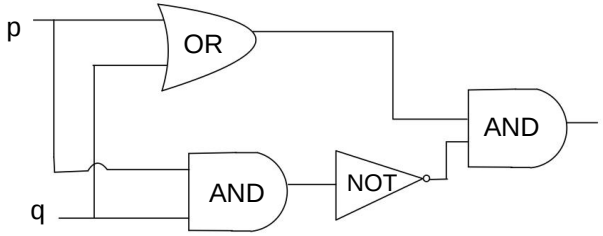


p	q	(p OR q) AND (NOT(p AND q))
1	1	
1	0	
0	1	
0	0	

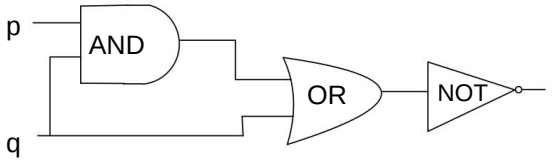


p	q	
1	1	
1	0	
0	1	
0	0	

EXERCISE 1- SOLUTION

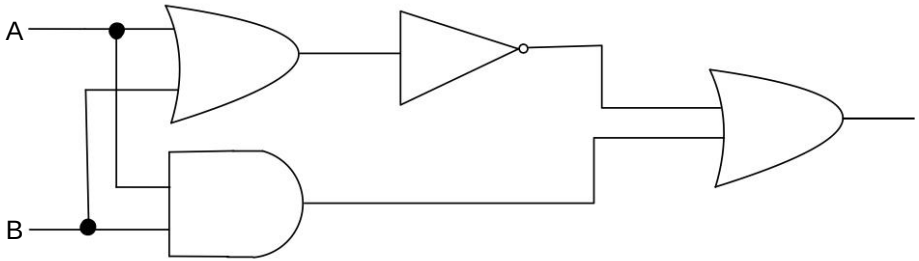


p	q	(p OR q) AND (NOT(p AND q))
1	1	0
1	0	1
0	1	1
0	0	0

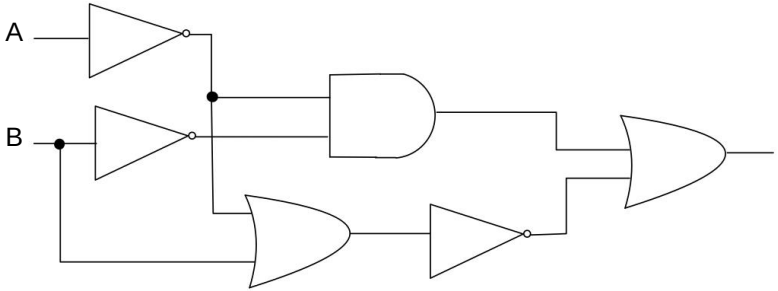


p	q	NOT ((p AND q) OR q)
1	1	0
1	0	1
0	1	0
0	0	1

EXERCISE -2

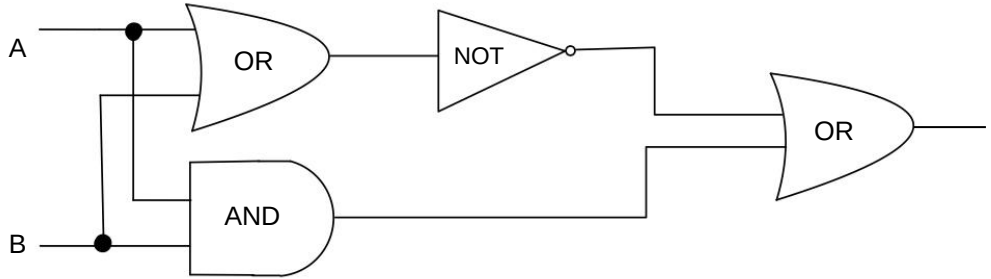


A	B	
1	1	
1	0	
0	1	
0	0	

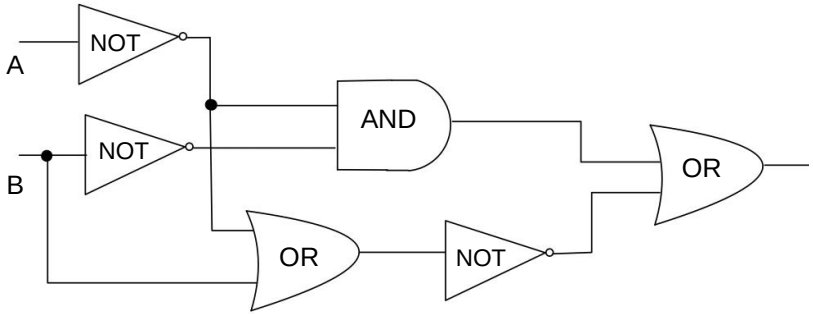


A	B	
1	1	
1	0	
0	1	
0	0	

EXERCISE - 2 (SOLUTION)



A	B	NOT[A OR B] OR (A AND B)
1	1	1
1	0	0
0	1	0
0	0	1



A	B	(NOT[A] AND NOT[B]) OR (NOT{(NOT[A]) OR (B)})
1	1	0
1	0	1
0	1	0
0	0	1

NYU CONCLUSION/CONTRIBUTIONS OF LESSON

- Most important concepts learned in: (i) lesson and (ii) task
- Contributions of lesson and task with respect to the entire PD program (only major/core contributions)
- How the information learned in this lesson will be beneficial for the next topic/lesson? (transition to next lesson)
- Important outcomes and findings?

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Thank You!

Questions and Feedback?