IDC102:Hands-on Electronics
Lecture - 1

IISER

Satyajit Jena, 09/05/2022

IDC102: Course Objectives

- Introduction to electronics.
- Learn basic electrical quantities
- Learn basic ideas about circuits

- Recognize discrete components in electronics.
- Recognize the laboratory equipment.
- Learn to use components
- Learn to use a multimeter

- Working experience with prototype board
- Assemble simple circuits over a PCB.

Supplement Lecture Notes:

- Basic – 1: SJ-20220509-IDC102-Supplement1-Introduction
- Basic – 2: SJ-20220509-IDC102-Supplement2-Introduction

  (Discussion and recap of several fundamental quantities)

- Basic – 3: SJ-20220509-IDC102-Supplement3-Introduction

  (Discussion related to DC and AC)

- Lab Equipment: SJ-20220509-IDC102-Supplement4-LabEquipments

  (Discussion related to measuring equipment and multimeters)

- Breadboard: SJ-20220509-IDC102-Supplement5-BreadBoard

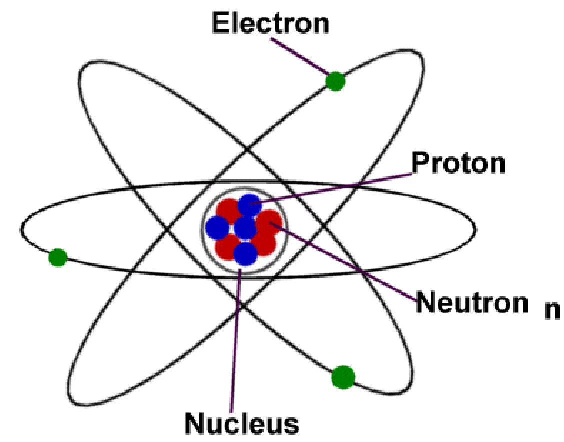
  (Discussion related to protoboards or breadboards and their connections)

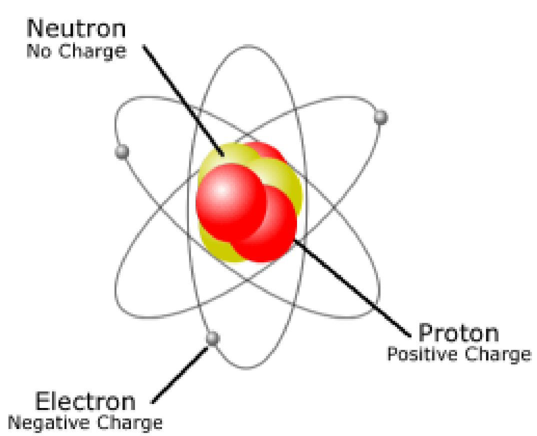
- General Definition
  - The science dealing with the development and application of devices and systems involving the flow of electrons in a vacuum, in gaseous media, and in semiconductors.
- Modern Definition
  - The science dealing with the development and application of devices and systems involving the flow of electrons in semiconductors.

IDC102: Electronics vs. Electrical

- According to Wikipedia
  - Electrical Engineering: is a field of engineering that generally deals with the study and application of electricity, electronics, and electromagnetism.
  - Electronic Engineering: is an engineering discipline where non-linear and active electrical components such as electron tubes, and semiconductor devices, especially transistors, diodes and integrated circuits, are utilized to design electronic circuits, devices and systems.
- Main Difference:
  - Electrical Engineering
    - Study and utilization/ Application of flow of electrons
  - Electronic Engineering
    - Study and utilization/ Application of flow of charges (Electrons or holes)

We know that matter is composed of atoms, which are composed of protons, neutrons, and electrons.



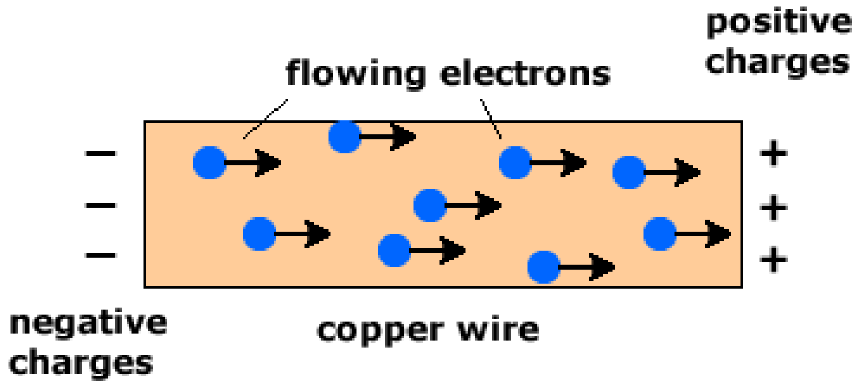


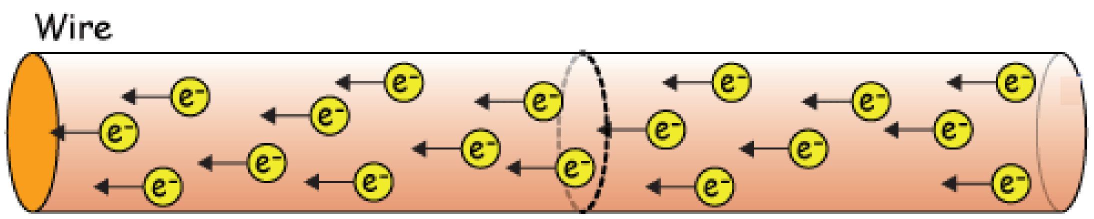
The protons are positively charged and are found "locked" in the nucleus with the neutrons.

The electrons are negatively charged and are moving around in the electron clouds and are not "locked" into position.

- In fact, electrons can and do move between atoms, and can be transferred to other materials and move around quite freely at times.

- This "free movement" of electrons is what we call electricity.
- The flow of charged particles is an electric current.





Current always flows from a positively charged source to a negatively charged source.

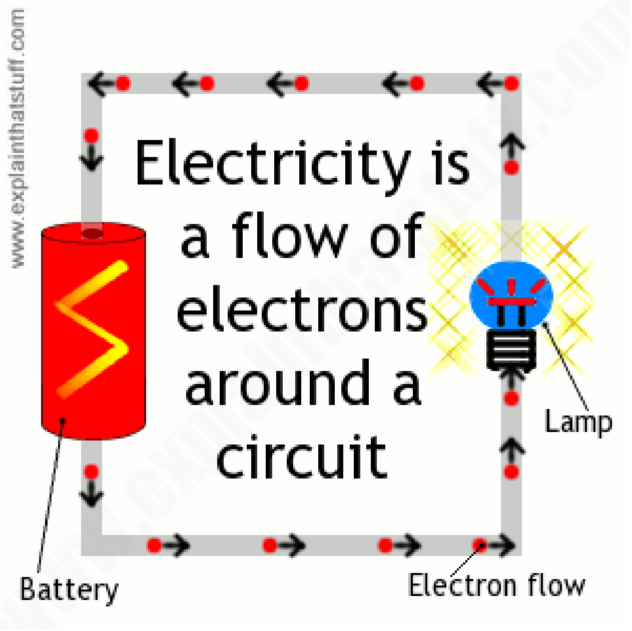
$$+ \rightarrow -$$

However, **electrons** always flow from negative (high concentration of electrons) to positive (low concentration of electrons).

$$- \rightarrow +$$

- The rate of movement of electrons can be measured over a certain amount of time.

- The current is defined as the rate of charge movement or the movement of electrons through an area over a given amount of time.



- Remember the Law of Conservation of Energy, which states that energy cannot be created or destroyed, but may only change form. This law applies here as electrical charges can be transferred between objects.

What is current?

When matter has an unequal number of protons (+) and electrons (-) it becomes charged. Two objects of different charge that come into contact with one another will cause a **flow of charge known as current**.

- Resistance - The opposition to the flow of electrical charge.
- Conduction - The movement of electrically charged particles through a transmission medium.
- Conductor - A material containing many free electrons that move through the material easily.

Conductors and Insulators

Electrical Conductor – Charge can flow easily.

Electrical Insulator – Charge cannot flow easily.

Why are some good conductors?

Conductors – electrons that are not tightly bound and free moving due to the sea of electrons.

IDC102: Basics

- Sometimes the flow of electrons is slowed down by any number of factors. These factors include:

1. Materials – what the electrons are moving through
2. Temperature – how warm or cold the materials are
3. Length – how far the electrons need to move
4. Cross section – how wide the area is the electrons are trying to move through

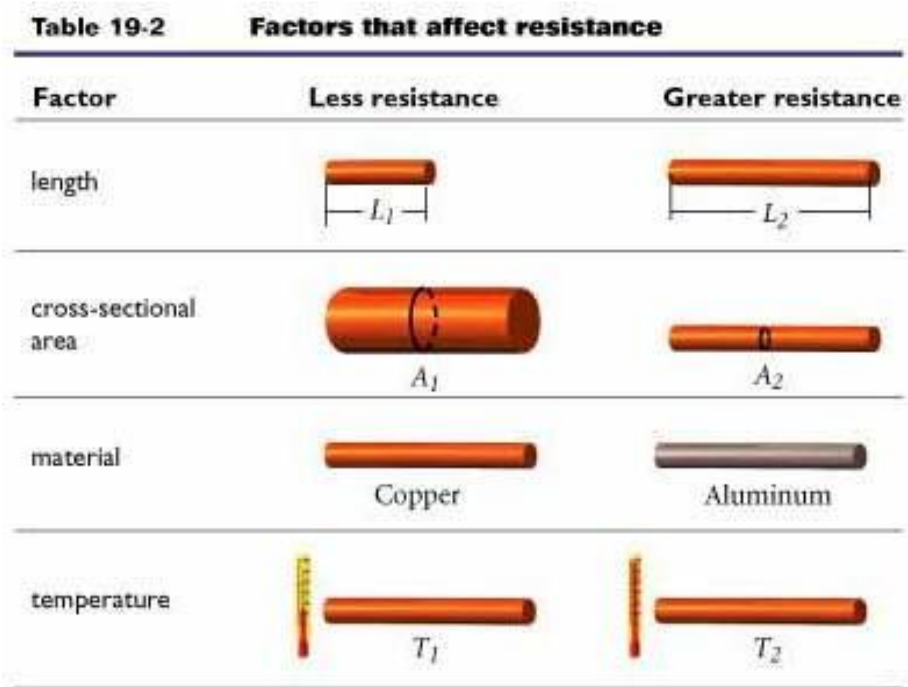


Table 19-2 Factors that affect resistance

Factor	Less resistance	Greater resistance
length	L_1	L_2
cross-sectional area	A_1	A_2
material	Copper	Aluminum
temperature	T_1	T_2

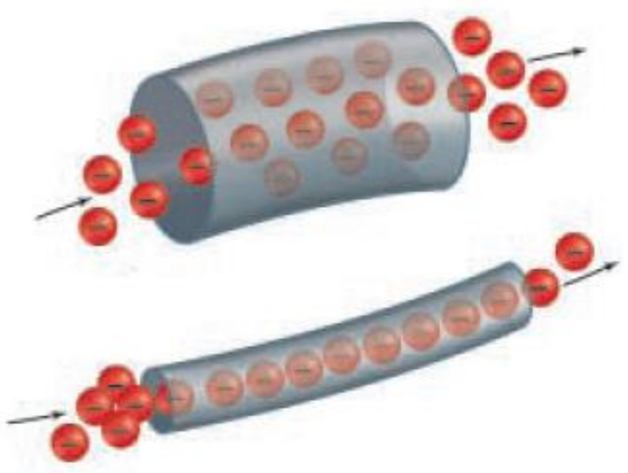
- ## Charge
  - Measured in Coulombs (C): number of electrons (or positive charges) present.
  - Charge of single electron is 1.602*10-19 C: One Coulomb = 6.24*1018 electrons.
  - Charge is always multiple of electron charge: charge cannot be created or destroyed, only transferred.
- ## Current
  - The movement of charge: we always note the direction of the equivalent positive charges, even if the moving charges are negative.
  - It is the time derivative of charge passing through a circuit branch
  - Unit is Ampere (A), is one Coulomb/second
  - Customarily represented by *i (AC)* or *I (DC)*.

$$i \equiv \frac{dq}{dt}$$

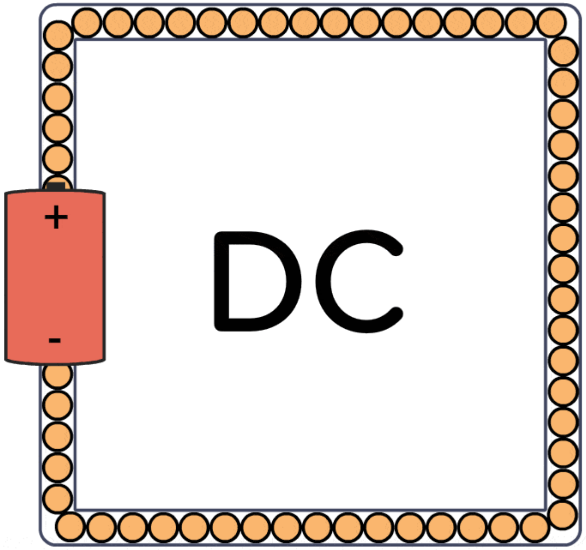
- ## Voltage (Potential Difference)
  - a *difference* in electric potential always taken between two points.
  - It is a line integral of the force exerted by an electric field on a unit charge.
  - Customarily represented by *u (AC)* or U (DC) or v and V alternativelly.
  - The SI unit is the Volt [V].
- ## Power
  - **Power** is the product of voltage by current.
  - It is the time derivative of energy delivered to or extracted from a circuit branch.
  - Customarily represented by *P* or S or W.
  - The SI unit is the Watt [W].

Difference b/t Volts and Amps

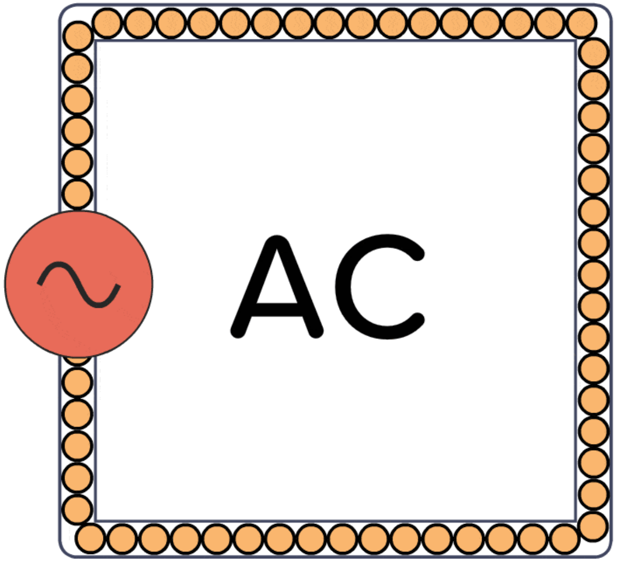
- Water equivalent
  - Amps measure how <u>much</u> water comes out of a hose.
  - Volts measure how <u>hard</u> or the pressure at which the water comes out of a hose.
  - Thus, the opposing force (which stops water) is just the pressure at which water comes out over how much of water is coming



AC vs DC: Current



- **Direct Current (DC)** is a current that remains constant with time is called
- A common source of DC is a battery.



- A current that varies sinusoidally with time is called **Alternating Current (AC)**
- Mains power is an example of AC

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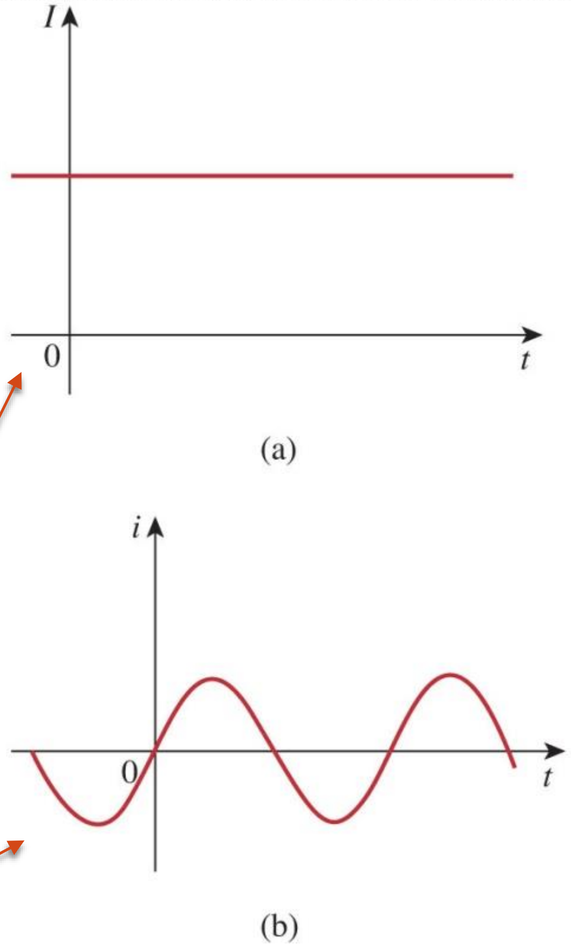


- A current that varies sinusoidally with time is called **Alternating Current (AC)**
- Mains power is an example of AC

What are these?

These are called wave forms!

AC: Summary

- AC signals are sinusoidal functions.
  - The mathematical description of the sinusoid includes the peak amplitude and the angular frequency and may include a phase angle.

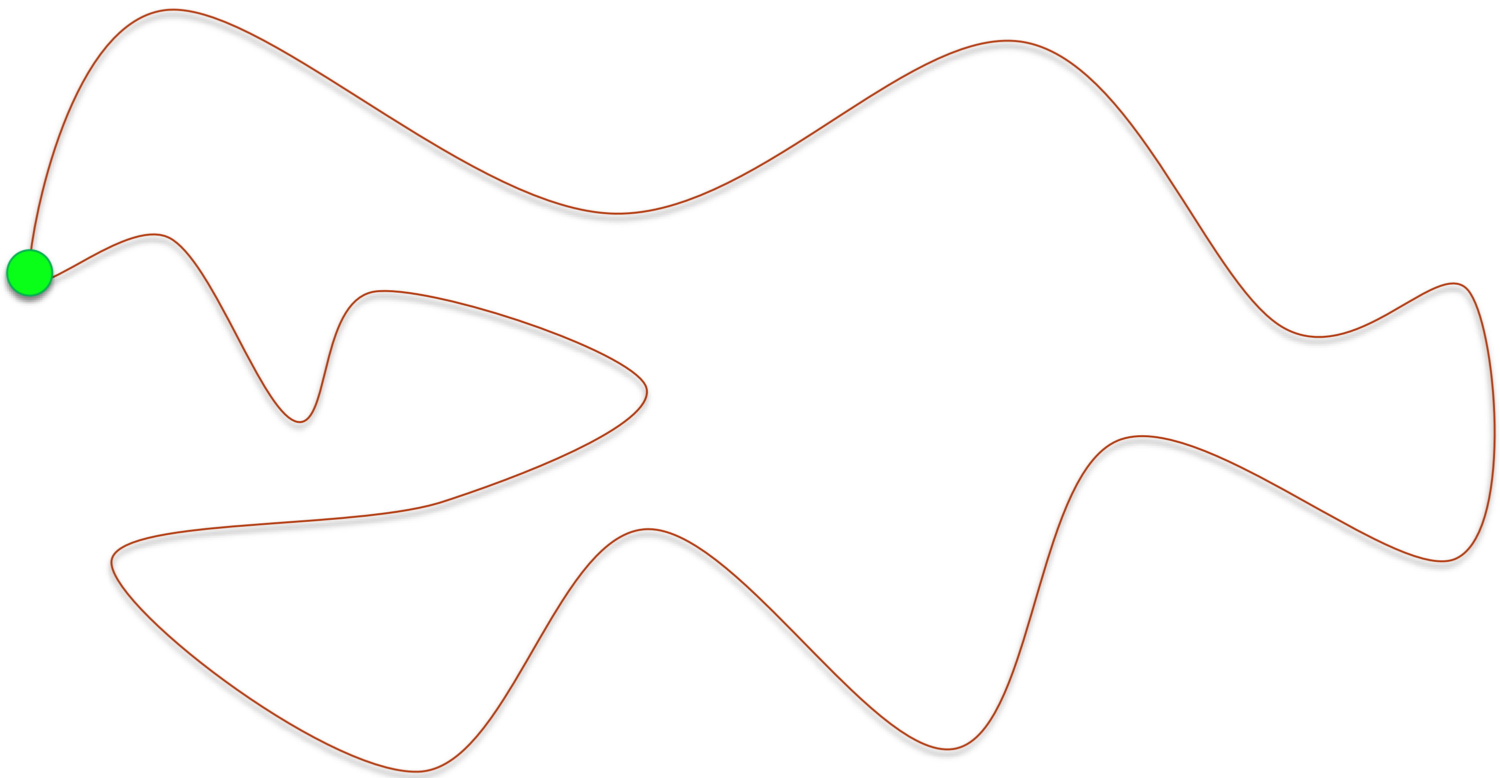
$$v(t) = V_p \sin(\omega t + \phi) \qquad \omega = 2\pi f = \frac{2\pi}{T}$$

- RMS values of a sinusoid are calculated using the formula

$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T [v(t)]^2 dt} \quad V_{RMS} = 0.707 V_p$$

- Phase angle for a sinusoid is calculated with respect to a reference.
  - A signal lags a reference when $f_{signal} - f_{reference} < 0^o$.
  - It leads a reference when $f_{signal} - f_{reference} > 0^o$.

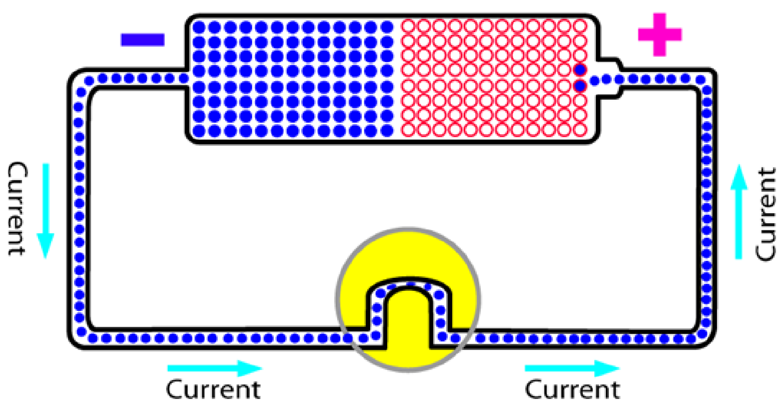
- Electric current always follows a fixed or defined path like a roller coaster



The path of electric charges (current) is called electric circuit

- The path of electric charges (current) is called electric circuit
- An electric circuit allows electrons to flow from a negative pole (excess electrons) to a positive pole (deficient in electrons)

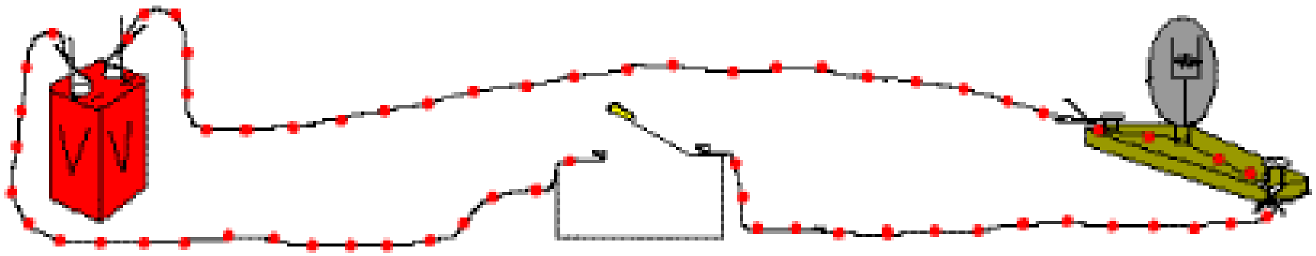
  - It provides the path for the electrons to move
  - It controls the movement of electrons



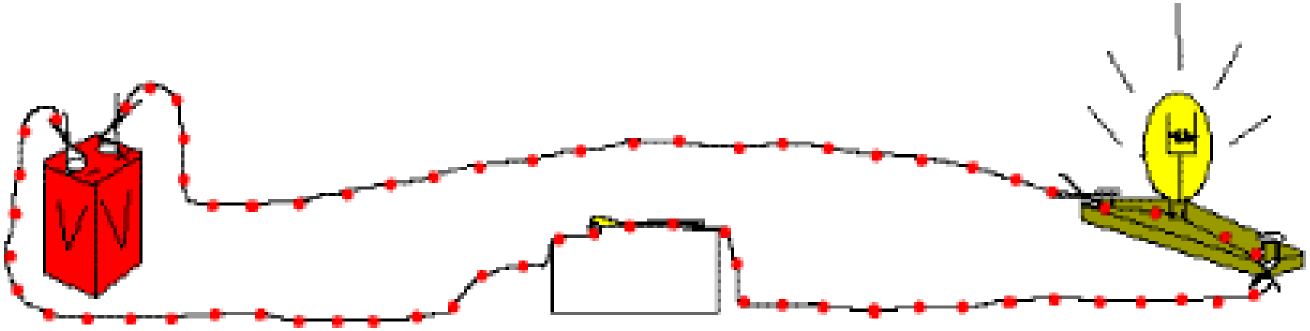
The interesting point is the path of electric circuit is always closed loop for electron to flow

Sometimes a circuit also contains a switch that is used to open and close a circuit.

OPEN CIRCUIT



CLOSED CIRCUIT

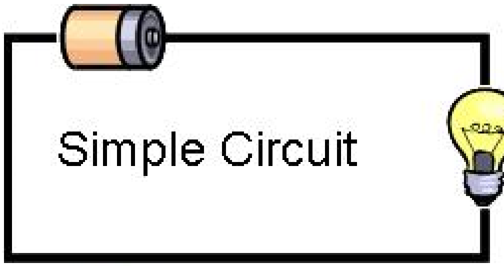


All circuits need three basic parts: an energy source, wires, and the object that is going to change the electrical energy into another form of energy (load).

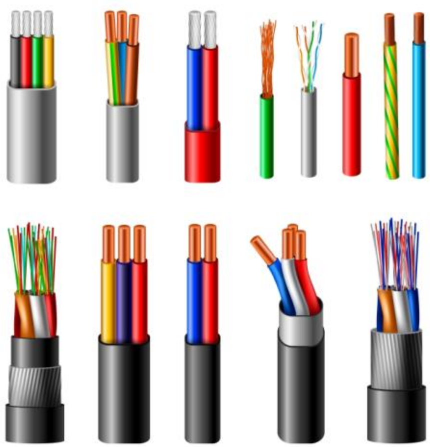
The circuit is established when there is a continuous path for electricity to travel from one end of the energy source to the other end.

Energy Source

Wire

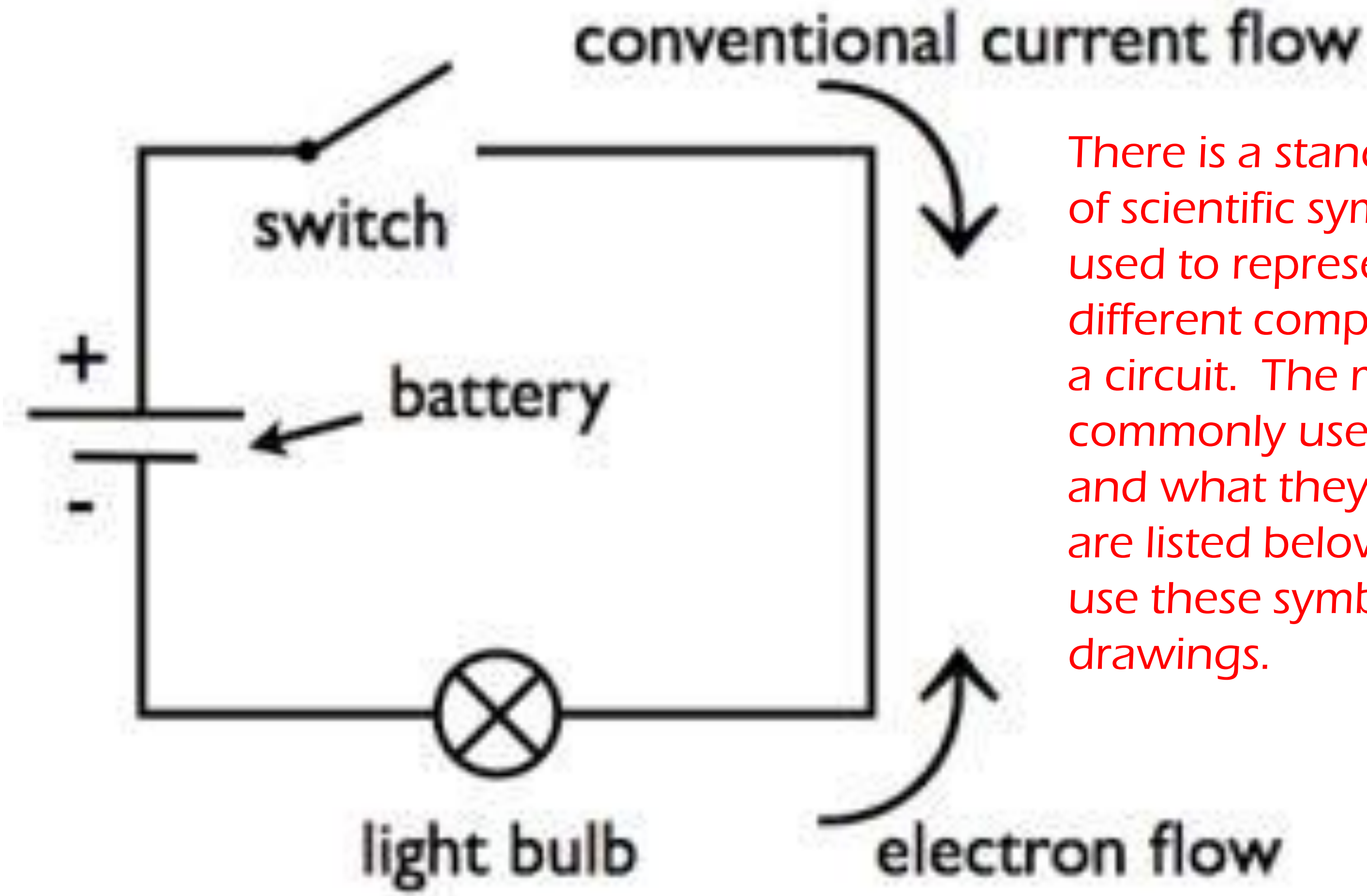


Load



IDC102 - Basics: Circuit Diagram

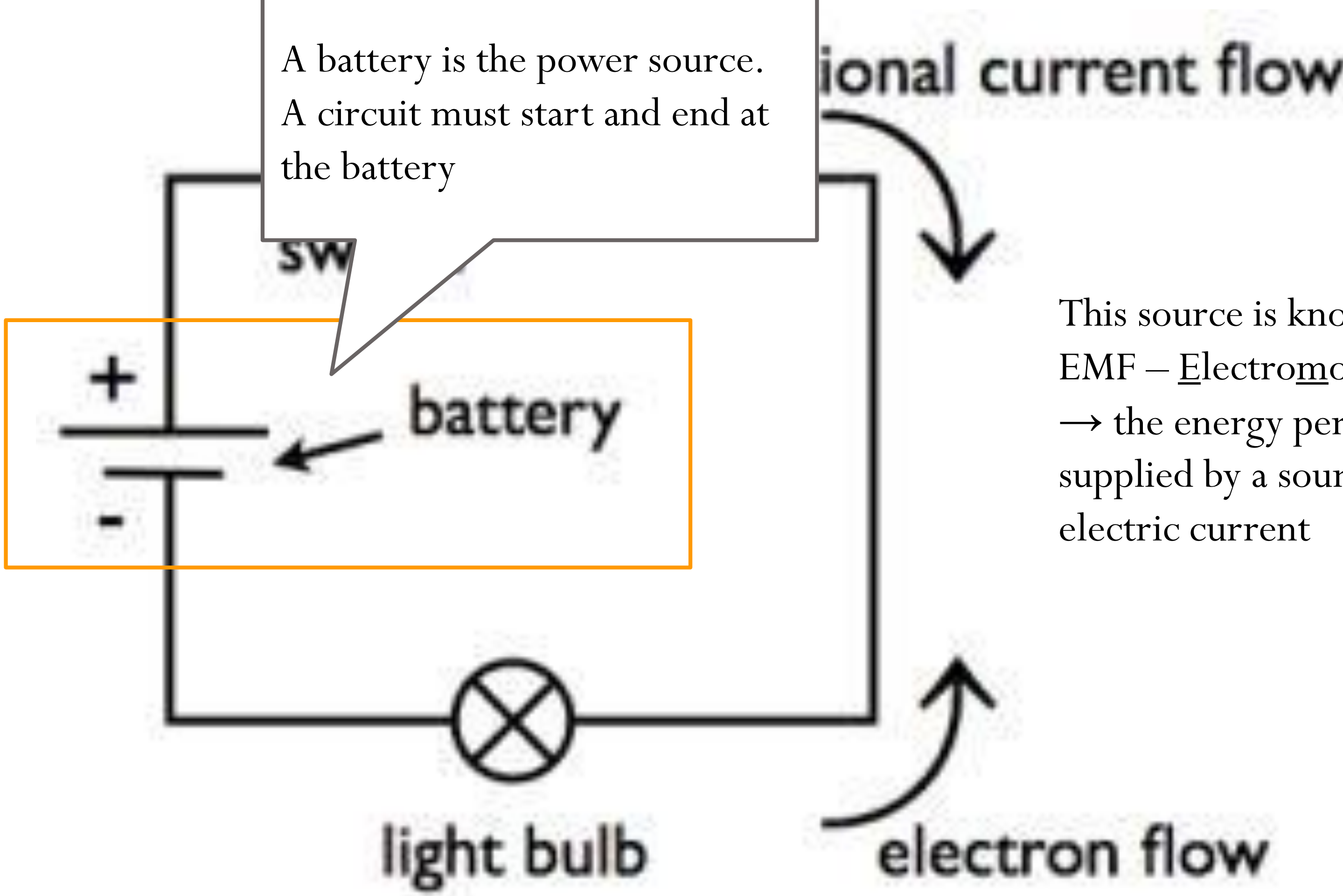
The drawings are called Schematic diagrams. Schematic diagrams are defined as graphical representations of an electrical circuit.



There is a standard set of scientific symbols used to represent different components in a circuit. The most commonly used symbols and what they represent are listed below, we will use these symbols in our drawings.

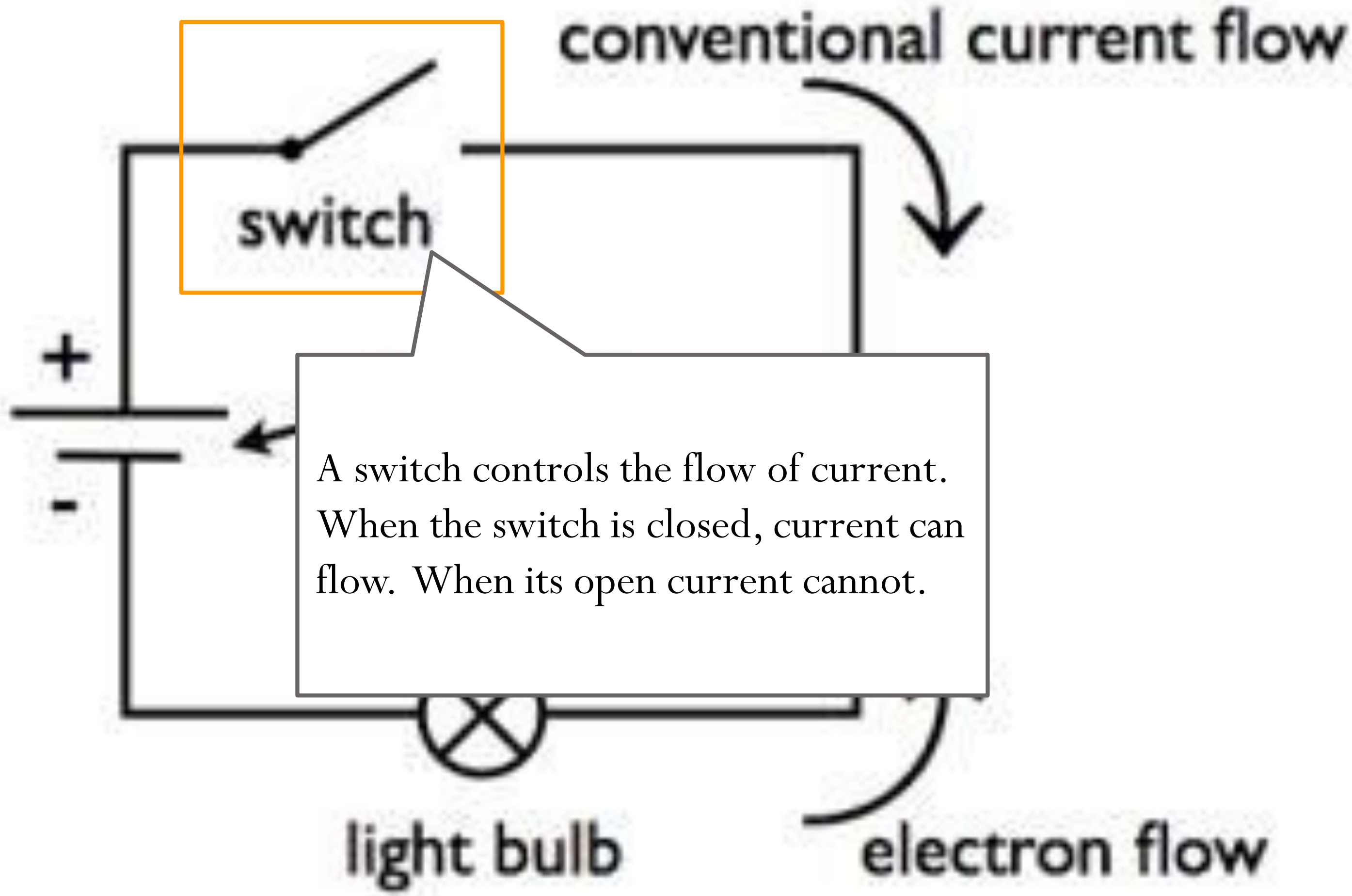
IDC102 - Basics: Circuit Diagram

A battery is the power source. A circuit must start and end at the battery

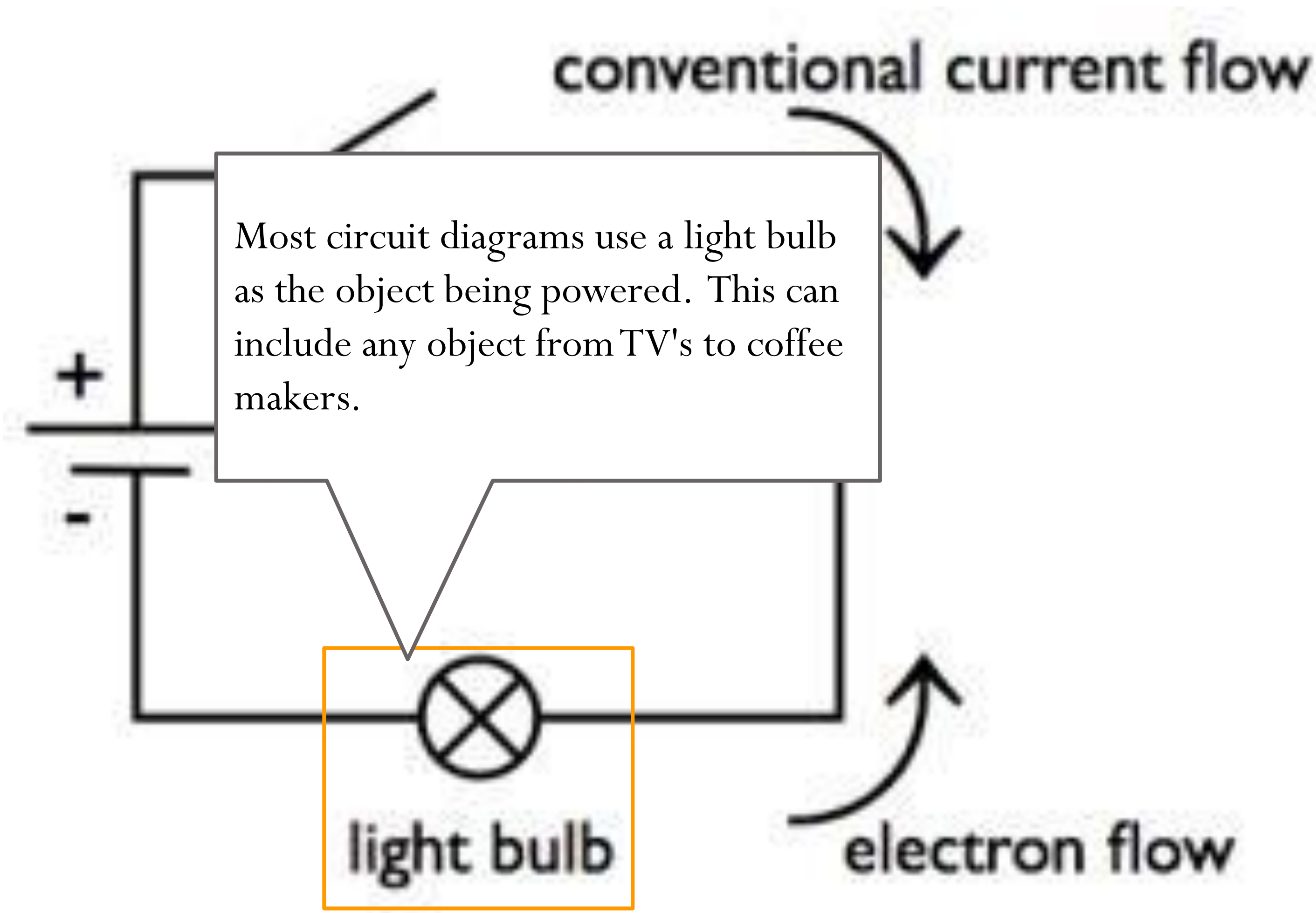


This source is known as the EMF – Electromotive force → the energy per unit charge supplied by a source of electric current

IDC102 - Basics: Circuit Diagram



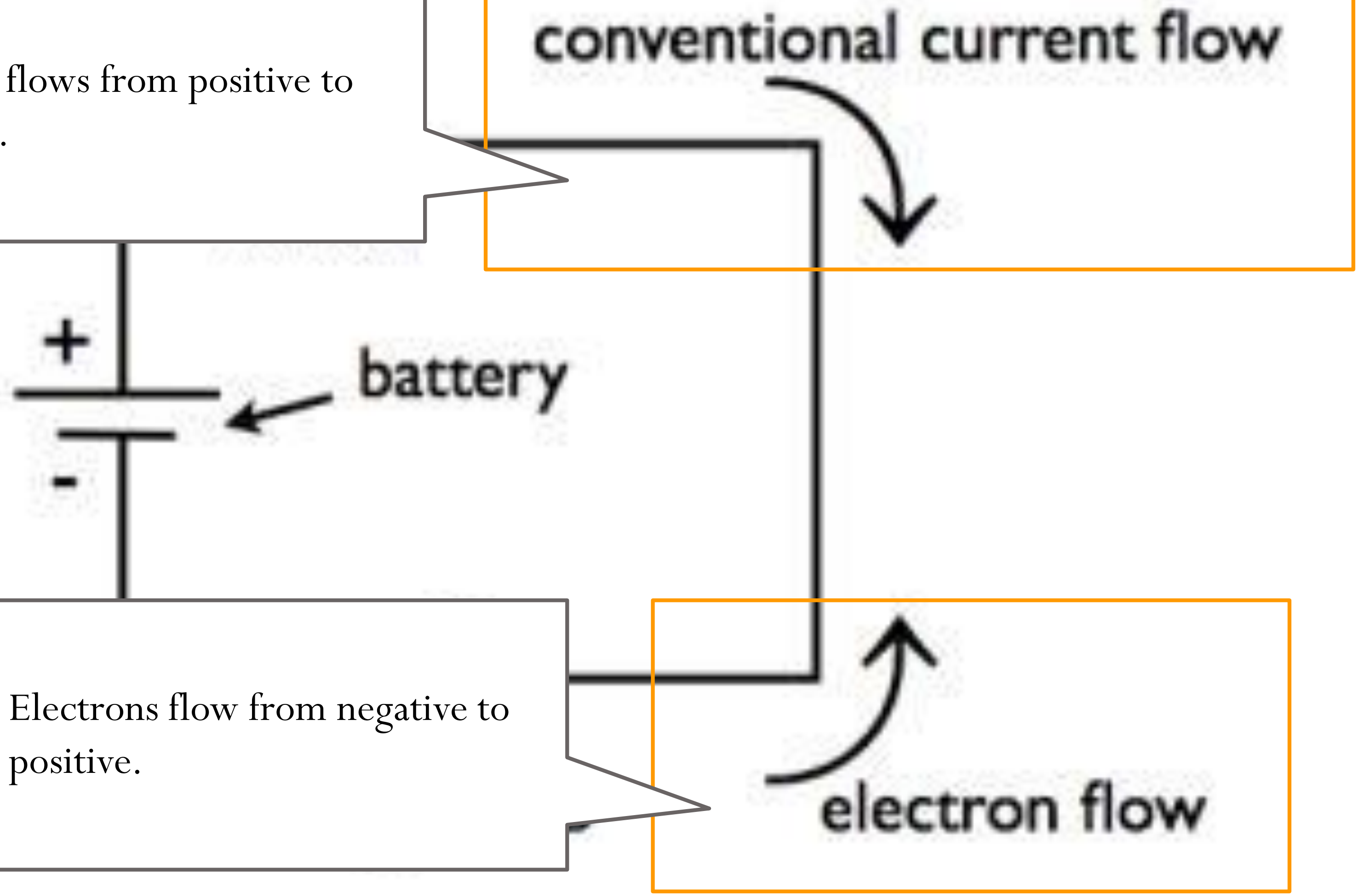
A switch controls the flow of current. When the switch is closed, current can flow. When its open current cannot.



Most circuit diagrams use a light bulb as the object being powered. This can include any object from TV's to coffee makers.

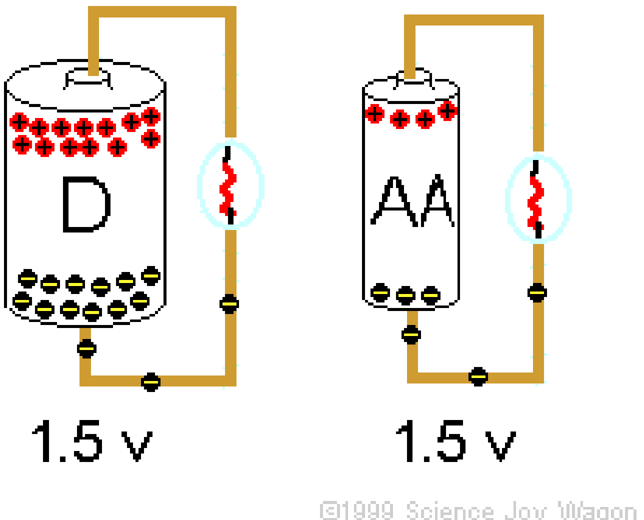
IDC102 - Basics: Circuit Diagram

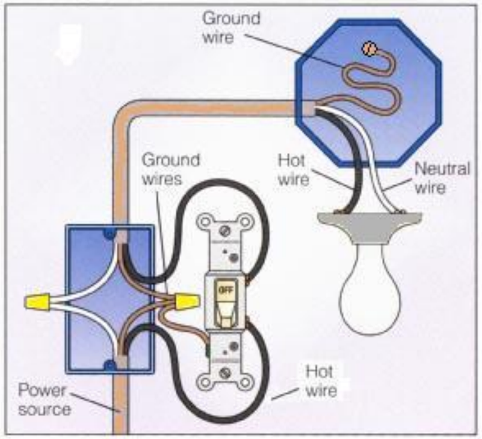
Current flows from positive to negative.

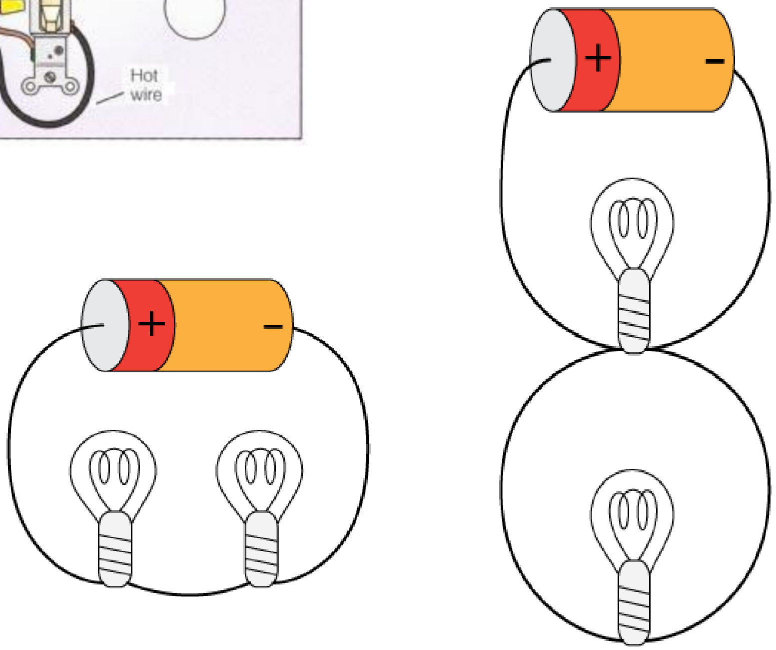


Electrons flow from negative to positive.

To be able to effectively use electricity, one must understand how electricity moves through different materials in a pathway.







Therefore, we need to know the types of circuits: Circuits are distinguished based on the way in which loads are connected.

IDC102 - Basics: Type of Circuit

There are three different types of electrical circuits:

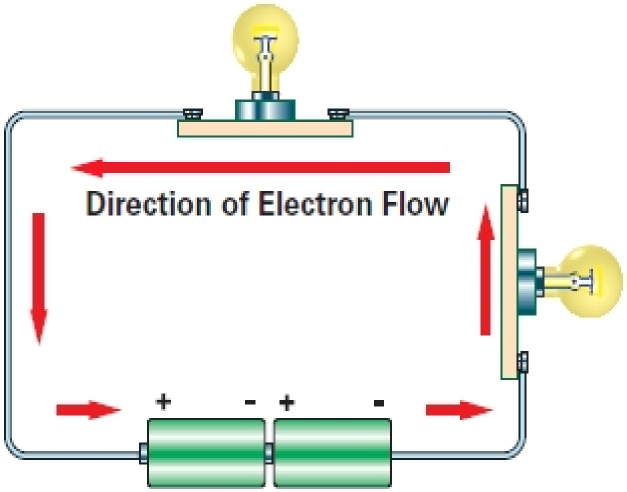
1. Series Circuits - Circuit (or portion of) in which there is a single conducting path without junctions for electricity to follow

2. Parallel Circuits - Circuit (or part of) where components are connected across common points and provides separate conducting paths for electricity to follow

3. Complex Circuits – Circuits with some segments being in series and other segment being in parallel to take advantage of the benefits of both

IDC102 - Basics: series Circuit

- Series Circuits - Circuit (or portion of) in which there is a single conducting path without junctions for electricity to follow
  - In a Series Circuit there is only one path for the electric current or electricity to flow.
  - All of the loads in a series circuit share the same current.
  - If there is any break in the circuit, the charges will stop flowing



Series Circuit

- In a series circuit there is one road and one road only. If part of the road is out, you cannot get where you want to go, no exceptions.

IDC102 - Basics: series Circuit

- All bulbs / resistors / components in series will have the same current. This is because the current can only flow as fast as the slowest (most resistant) component will allow.

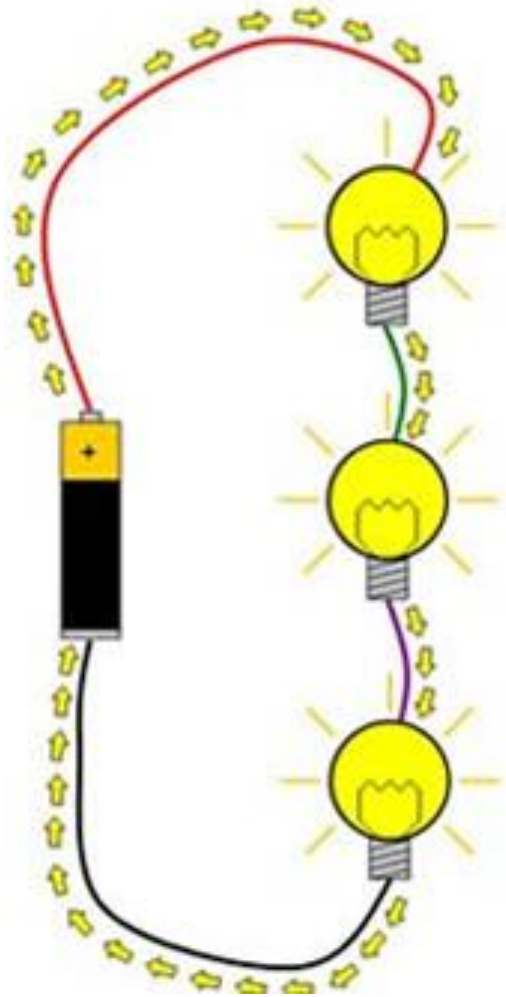
- The total current in a series circuit depends on the number of resistors present and resistance of each.
- Below is a list of advantages and disadvantages of series circuits (notice some may be both)

- Advantage of series circuits:

  1. Good for regulating current (all parts have same current)

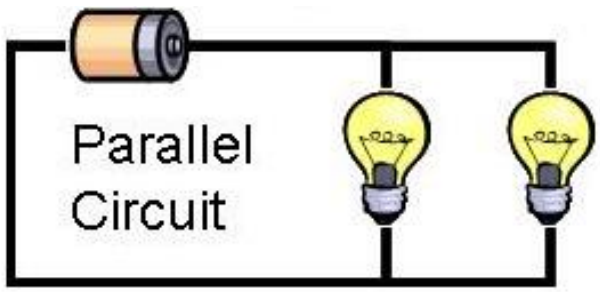
  2. Good for reducing current on individual parts

  3. Current stops if a component breaks



IDC102 - Basics: Parallel Circuit

- Parallel Circuits - Circuit (or part of) where components are connected across common points and provides separate conducting paths for electricity to follow
  - In a Parallel Circuit there is more than one path for the electric current or electricity to flow.
  - The electric current branches so that electrons flow through each of the paths
  - If one path is broken, electrons continue to flow to the other paths



- In a parallel circuit there is more than one road you can use as a possible route to the store. If one part of the road is out, you can choose a detour around it to still get where you want to go, or if the whole road is working, you can choose your path among several to get to the store.

IDC102 - Basics: Parallel Circuit

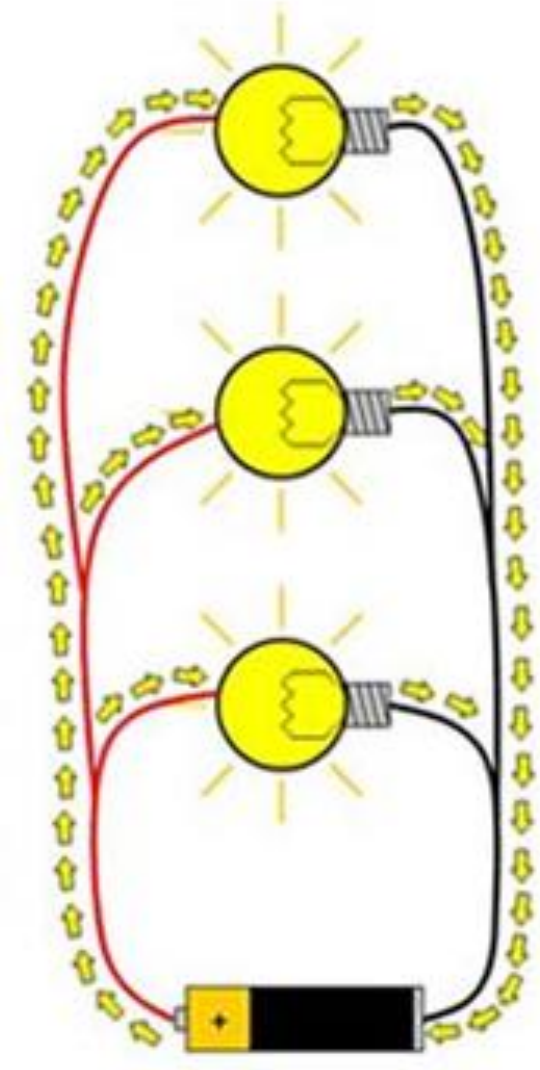
- Parallel circuits give multiple alternate pathways for current flow

- Advantages of parallel:
  - Parallel circuits do not require all elements to conduct
  - One part can malfunction and the rest will continue to work
  - Potential difference does not change for all components when one component fails

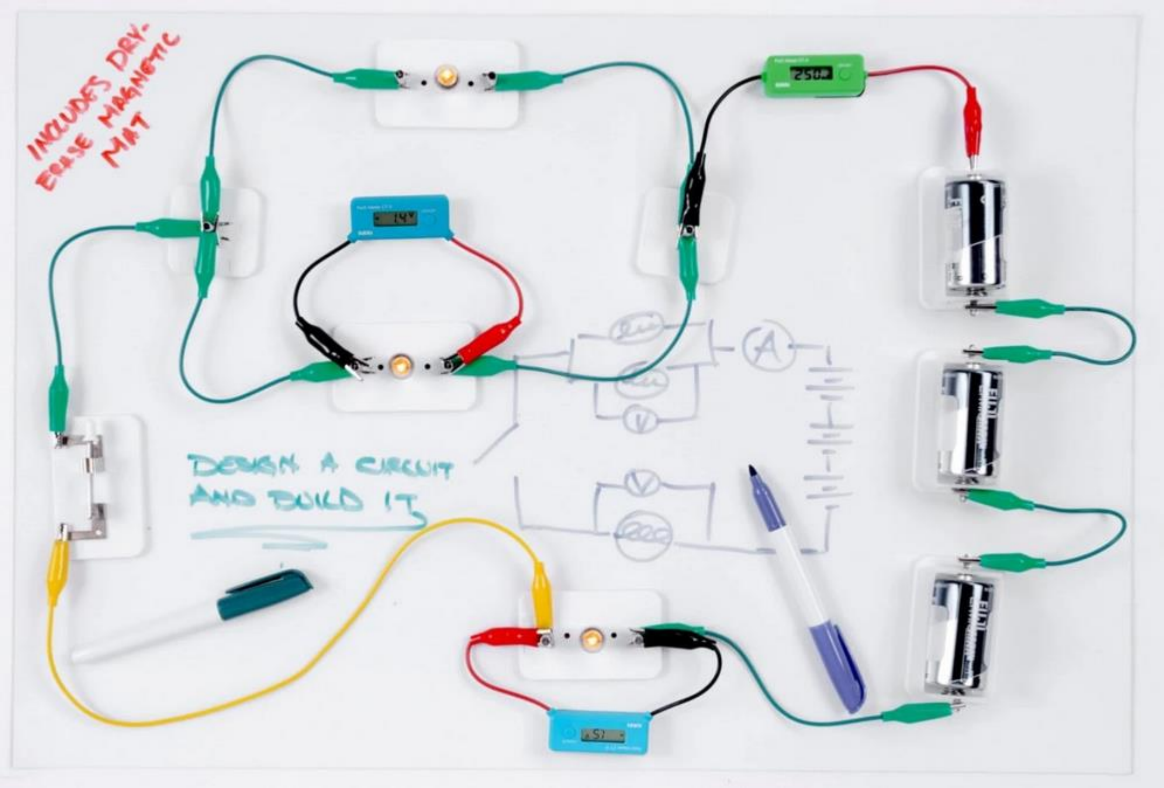
- The sum of currents in parallel resistors = total current

- Disadvantages of parallel:

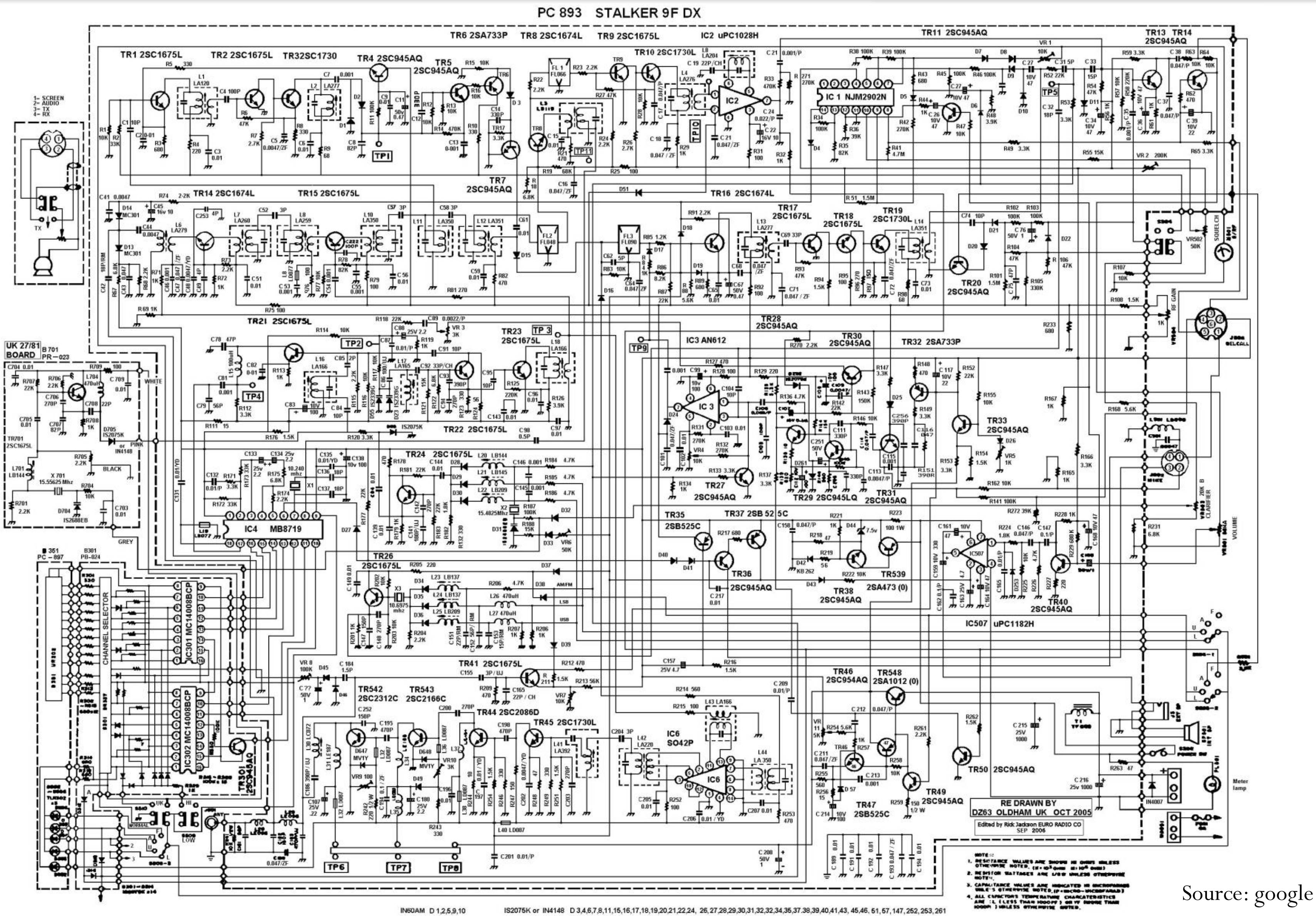
  1. Current will change if one component fails
  2. Current different in all components



- Complex Circuits - Circuit where components are connected both parallelly and in series which provides a complex conducting paths for electricity to follow

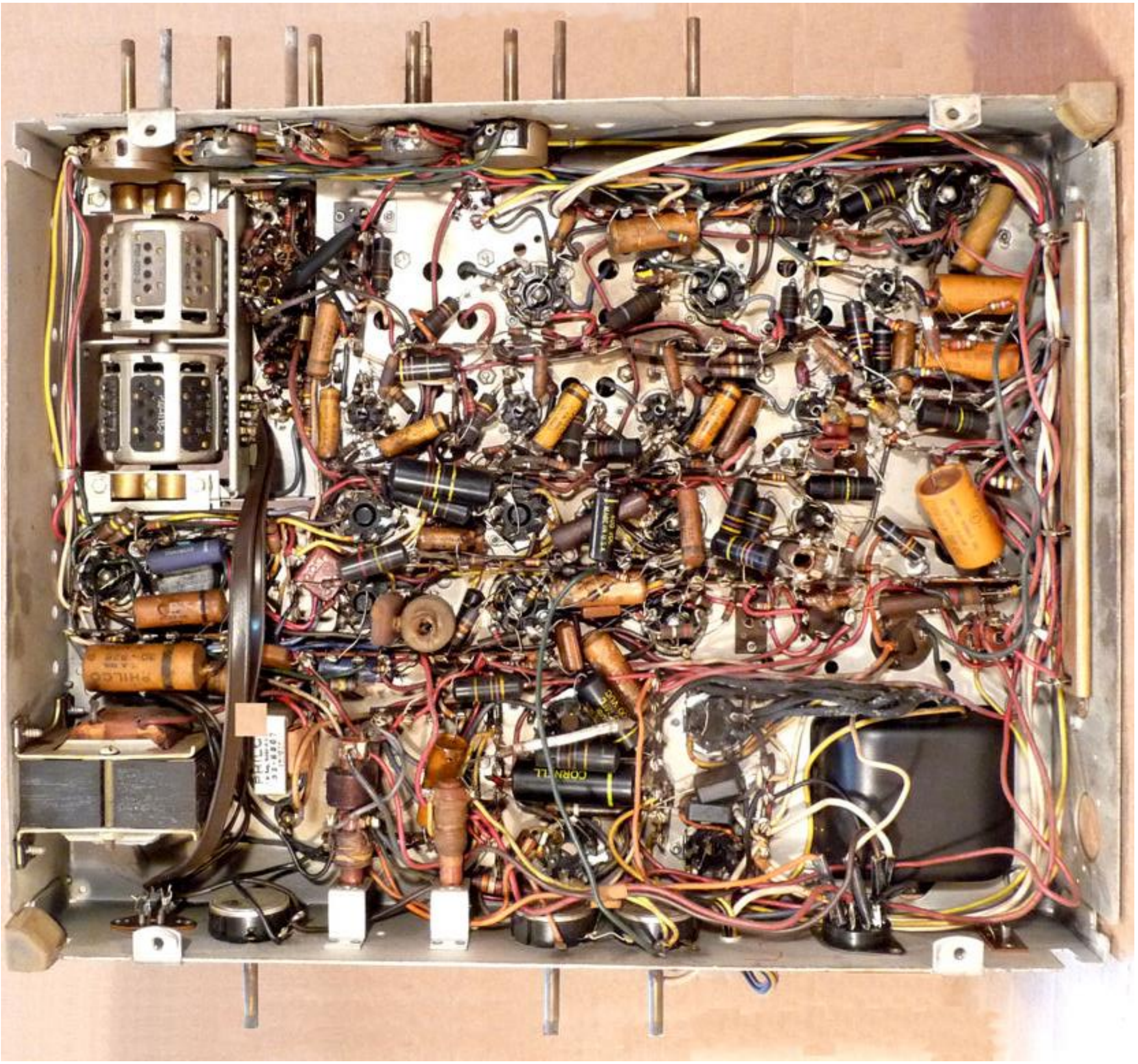


A complex circuit



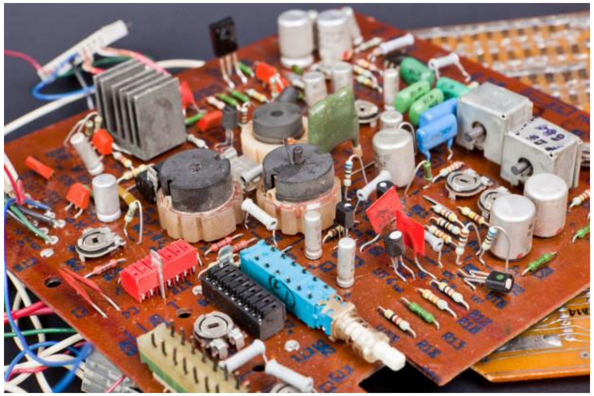
Source: google

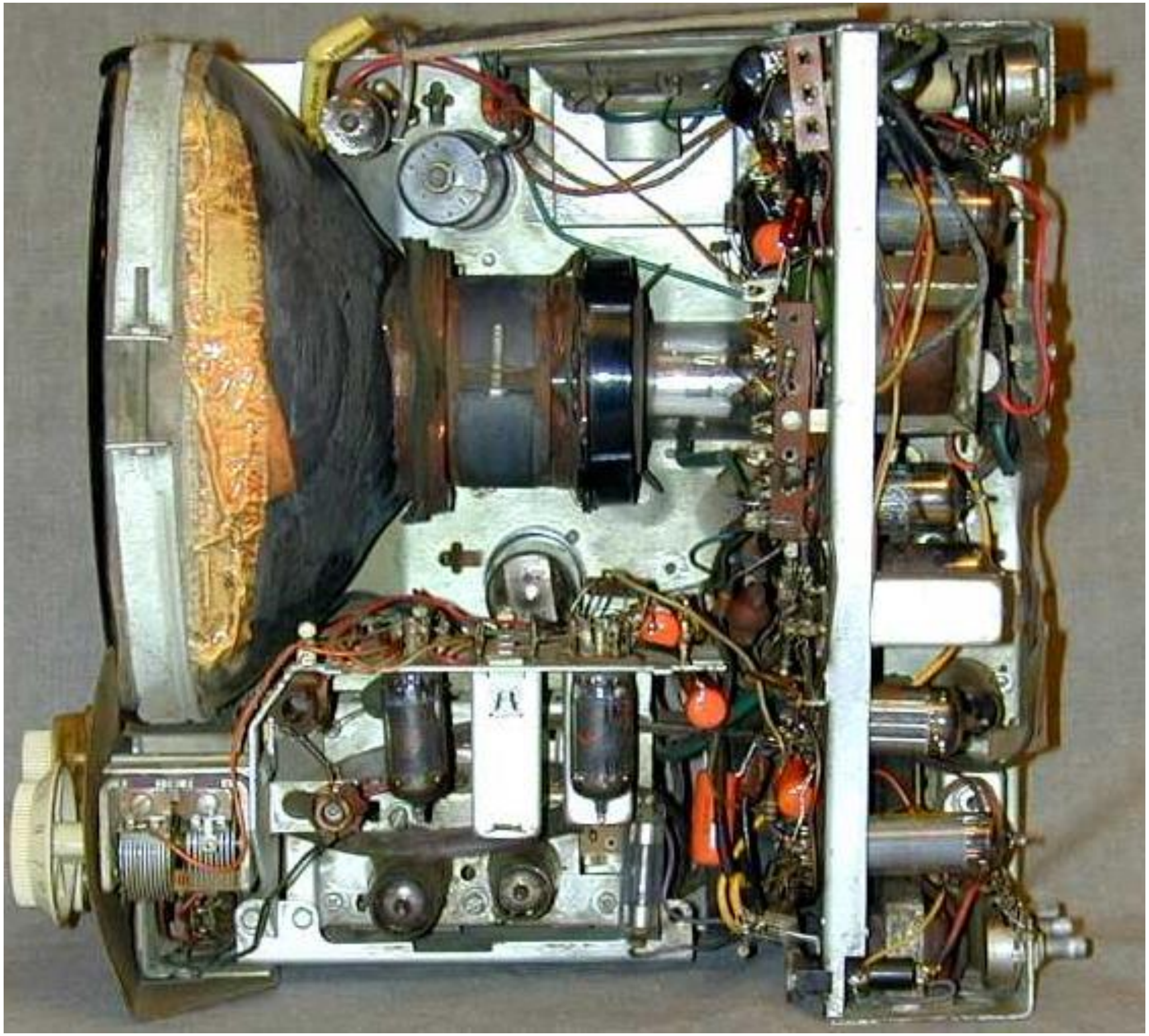
Some Circuit Board



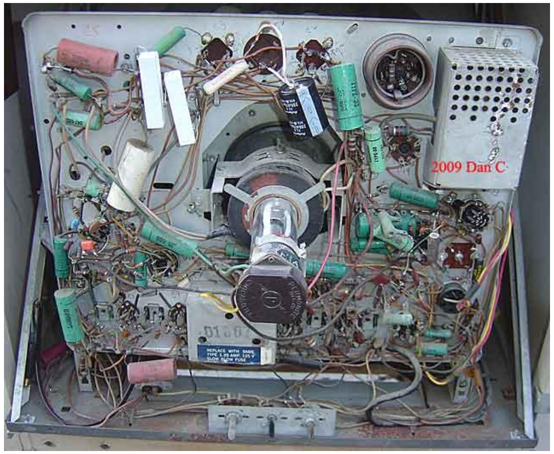
Old Harman Kardon Stereo Box, hand Soldered

Old Circuit: 1990s

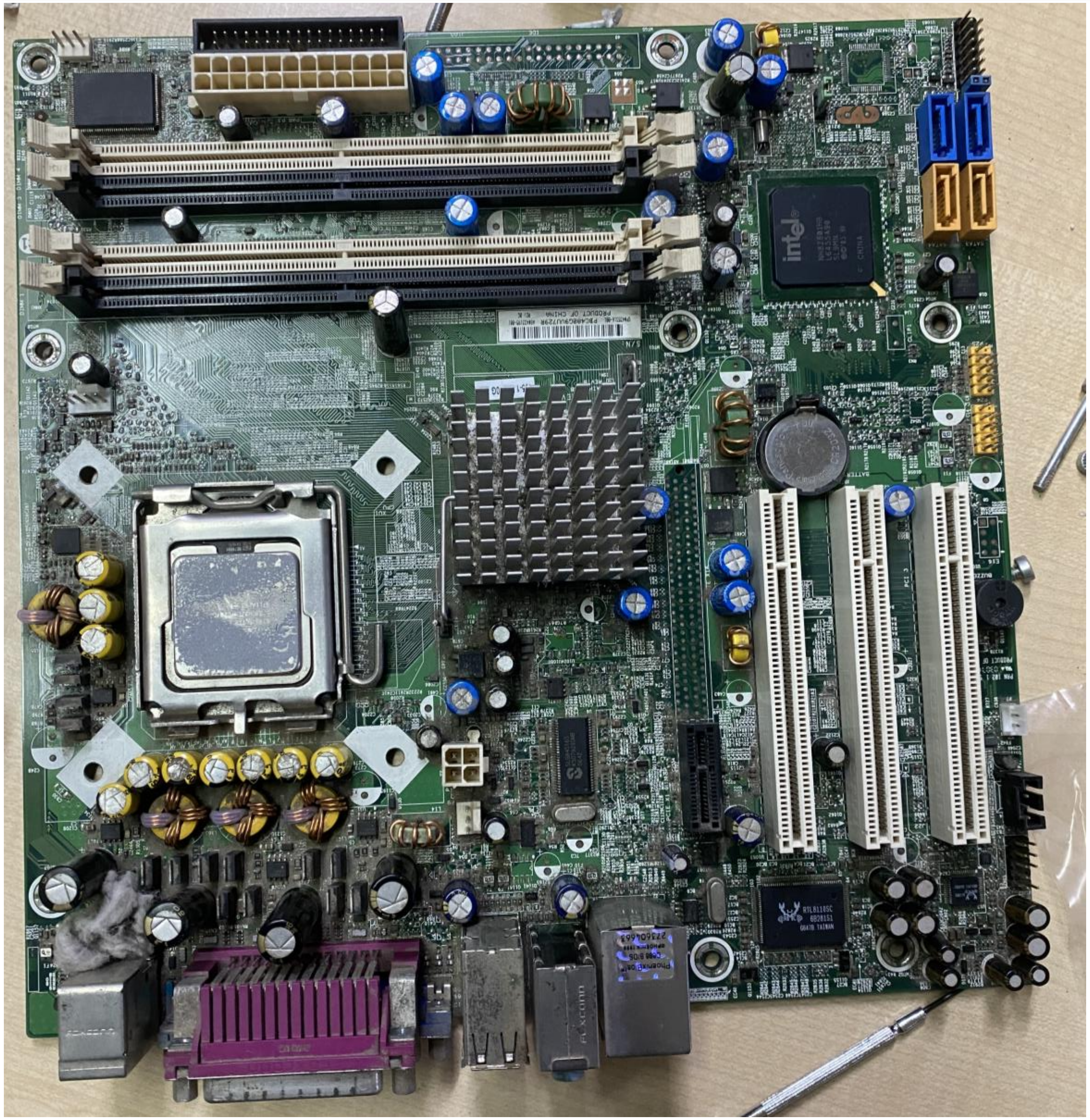


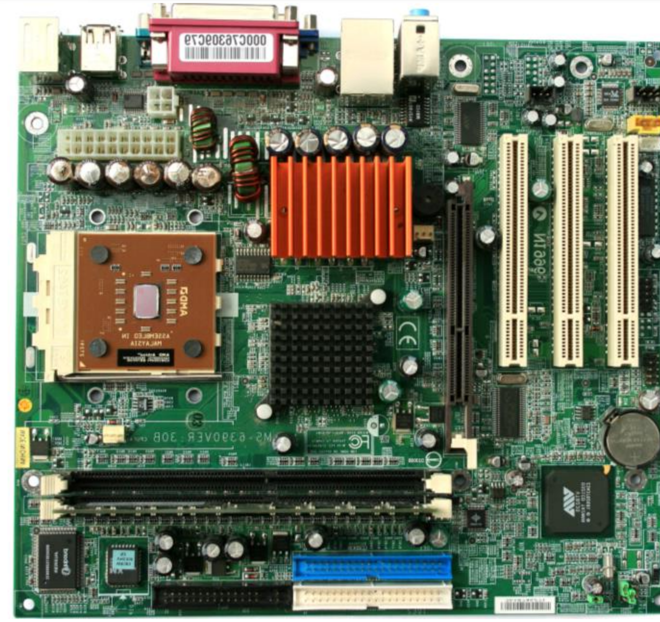


Any Old TV

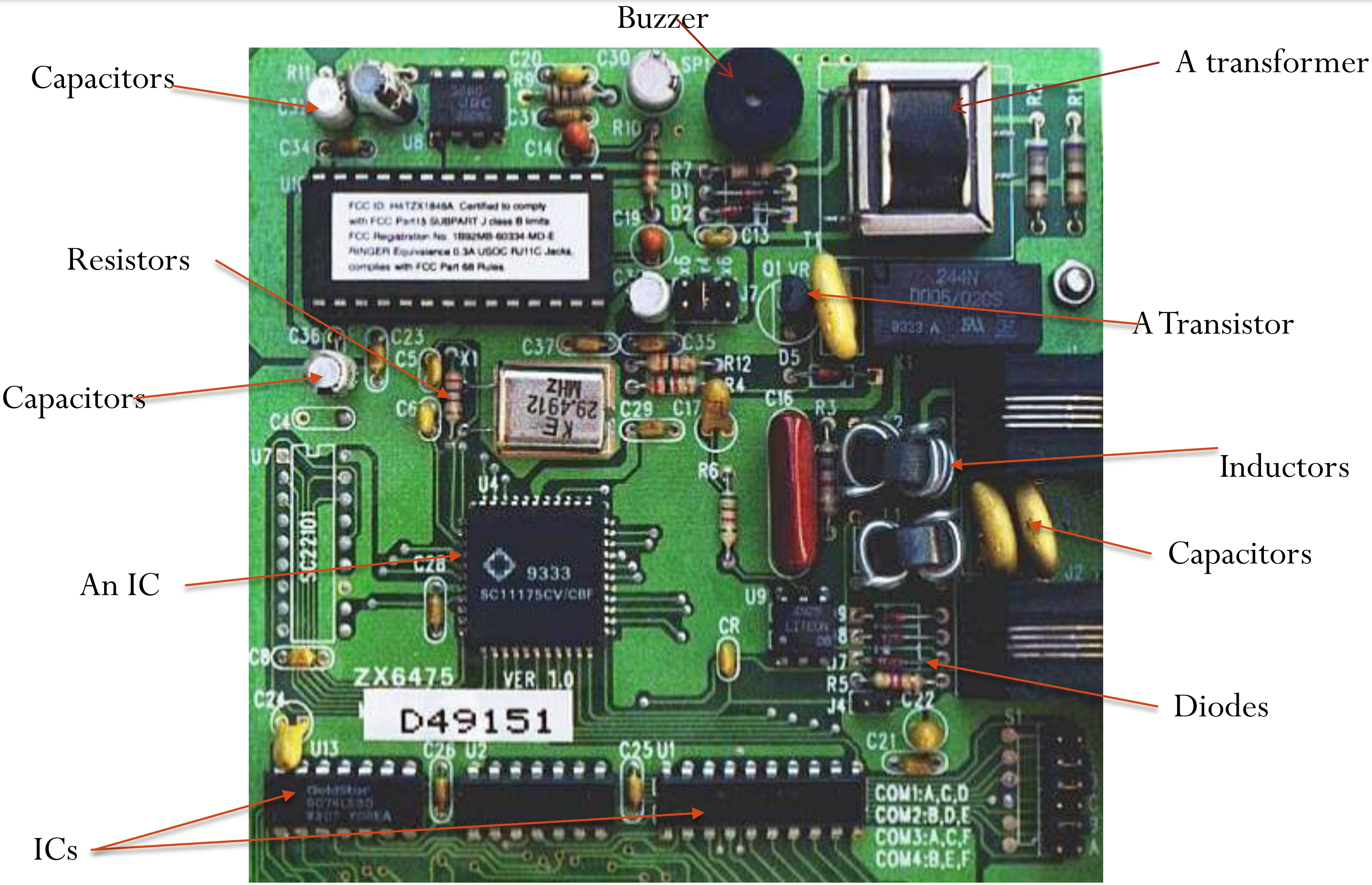


Electronics: A Computer Circuit Board





What are these?



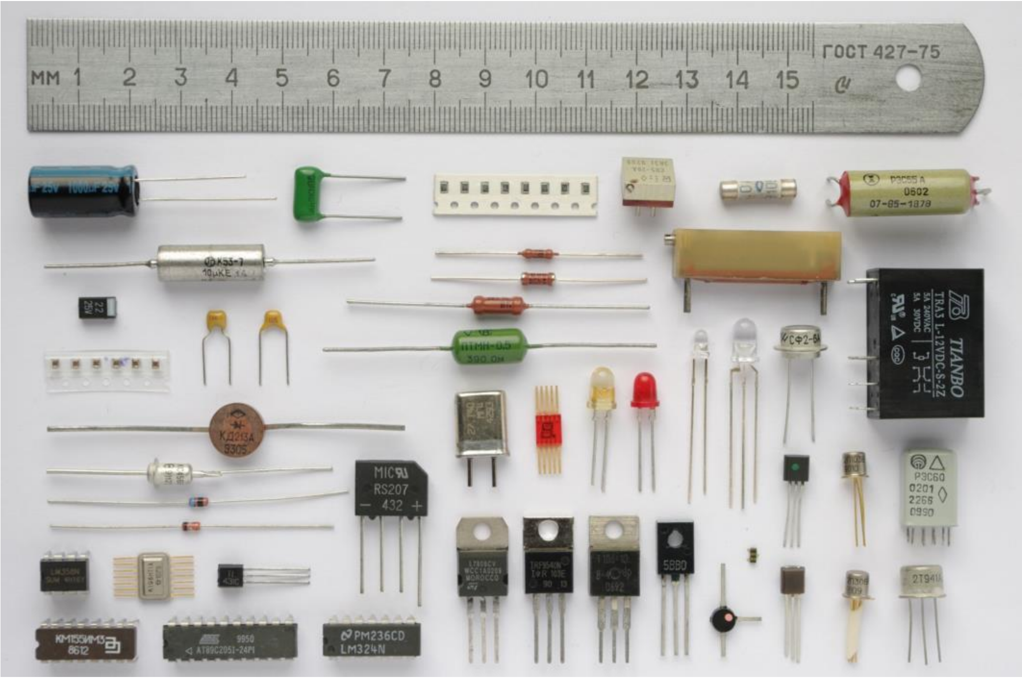
Components

An electronic component is any physical entity in an electronic system used to affect the electrons or their associated fields in a manner consistent with the intended function of the electronic system.

Components are generally intended to be connected together, usually by being soldered to a printed circuit board (PCB), to create an electronic circuit with a particular function (for example an amplifier, radio receiver, or oscillator).

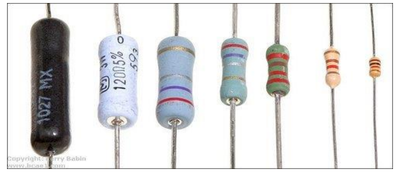
Components may be packaged singly, or in more complex groups as integrated circuits. Some common electronic components are capacitors, inductors, resistors, diodes, transistors, etc. Components are often categorized as active (e.g. transistors and thyristors) or passive

Each discrete component has a specific symbol when represented on a schematic diagram.

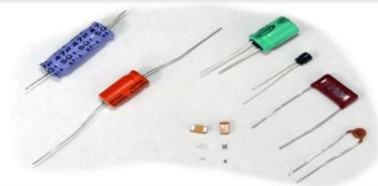


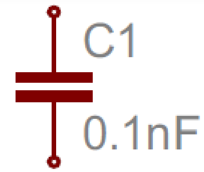
Components

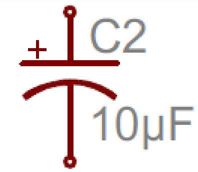
Resistor



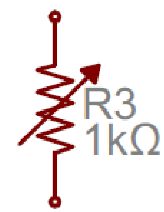
Capacitors

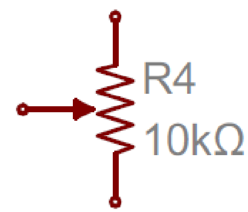






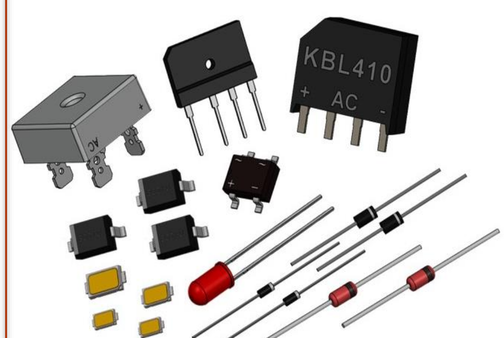
Variable Resistor

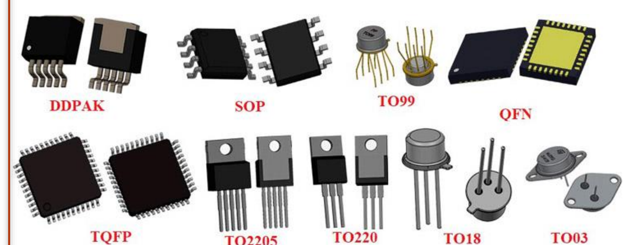




Inductors

Diodes





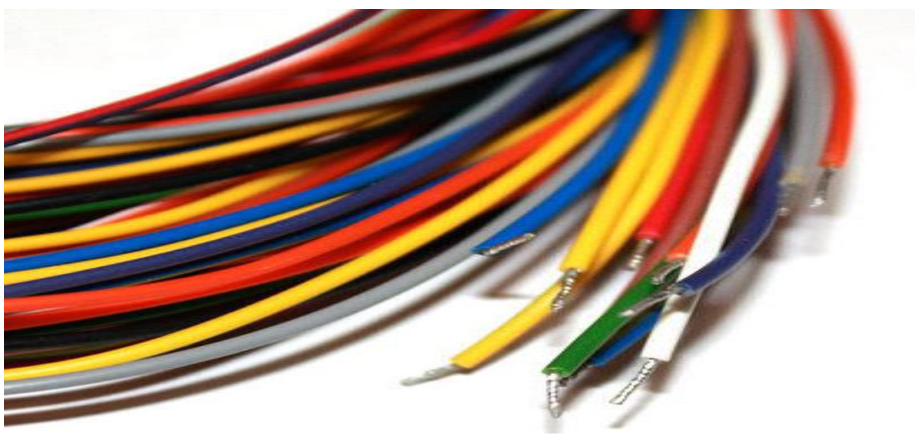
Transistor and IC

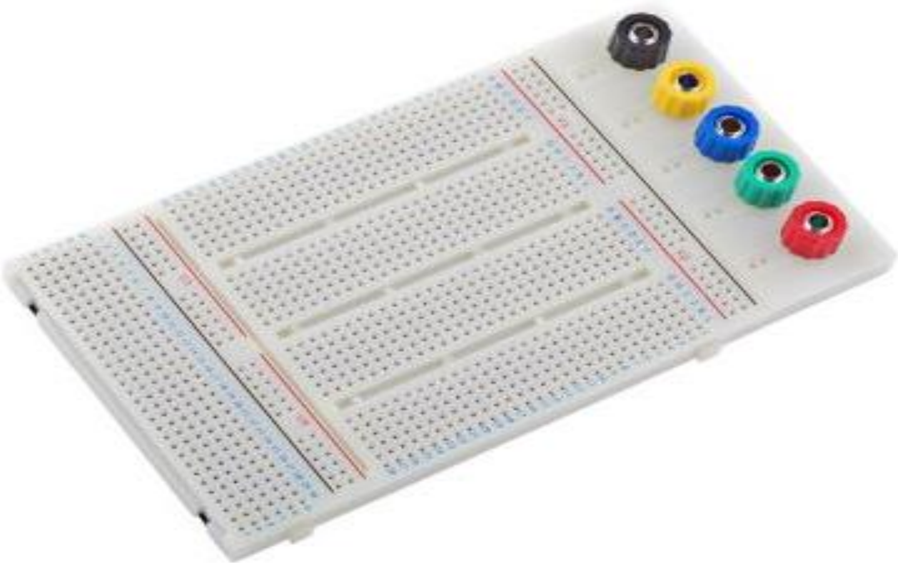
Other Components

In order to connect things together using a breadboard, you need to use a wire.

Wires are nice because they allow you to connect things without adding virtually no resistance to the circuit. This allows you to be flexible as to where you place parts because you can connect them together later with wire. It also allows you to connect a part to multiple other parts.

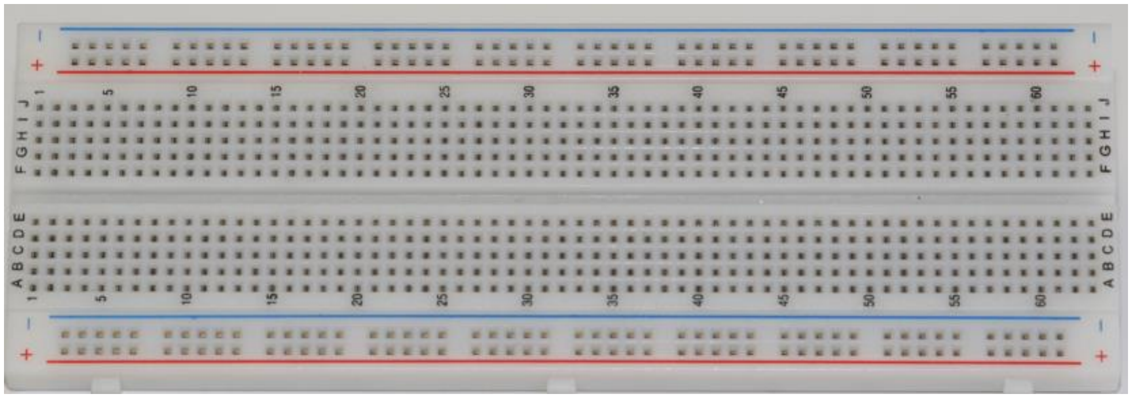
Breadboards are special boards for prototyping electronics. They are covered with a grid of holes, which are split into electrically continuous rows.

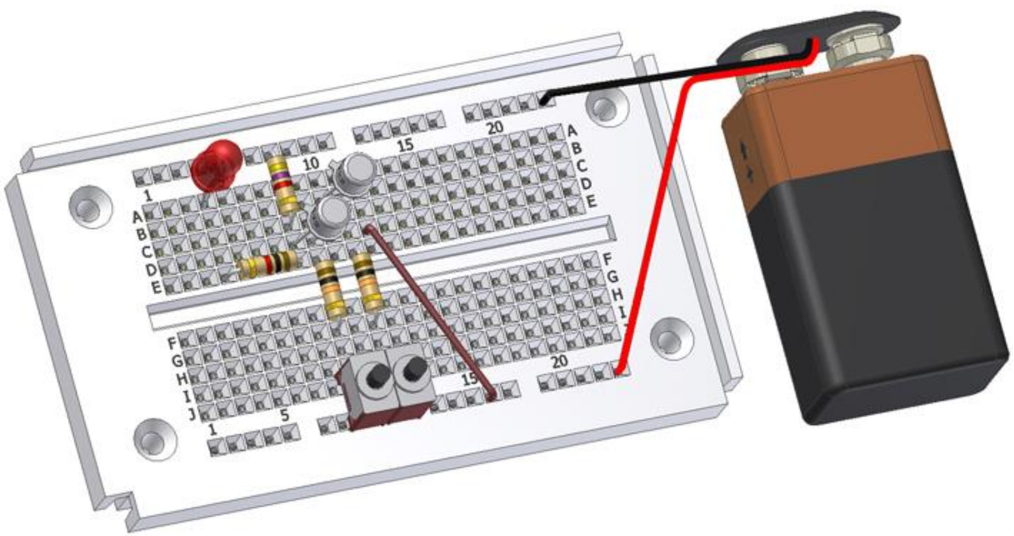


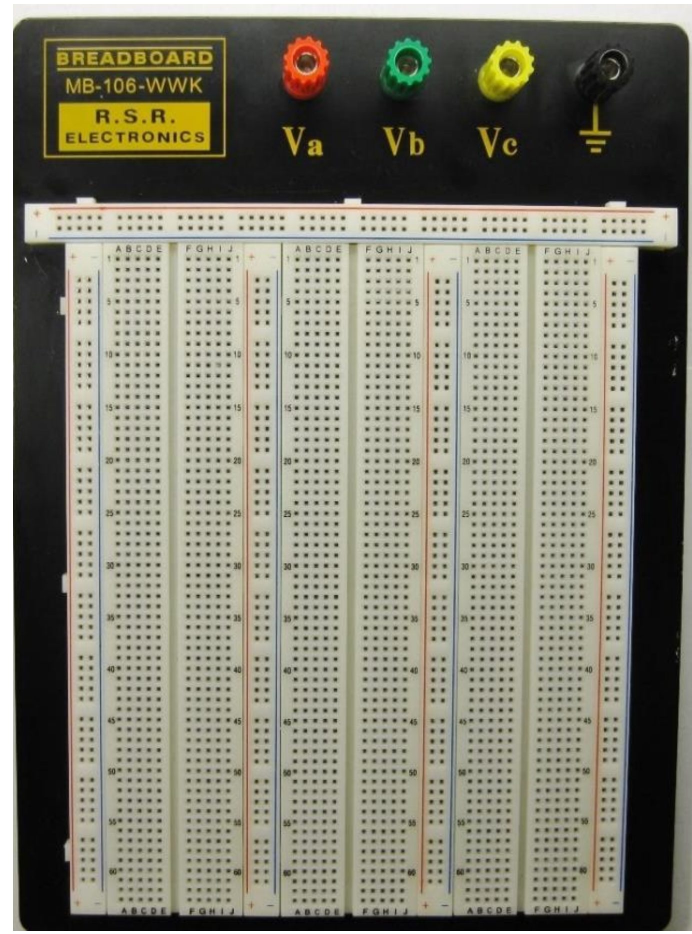


Breadboard

- A breadboard, sometimes called a protoboard, is a reusable platform to temporarily build electronic circuits.

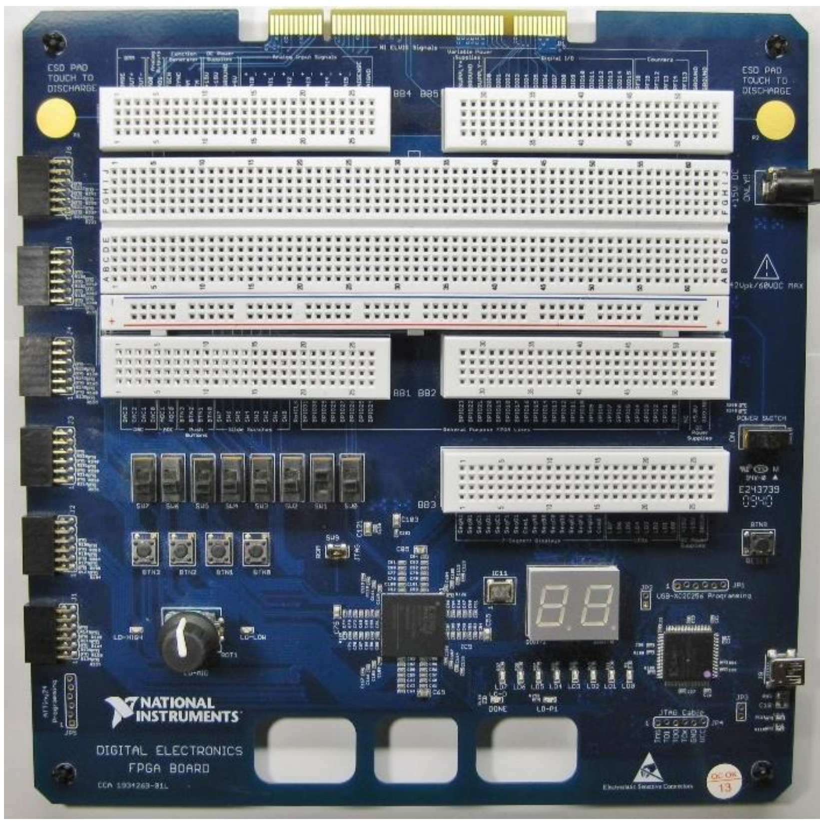


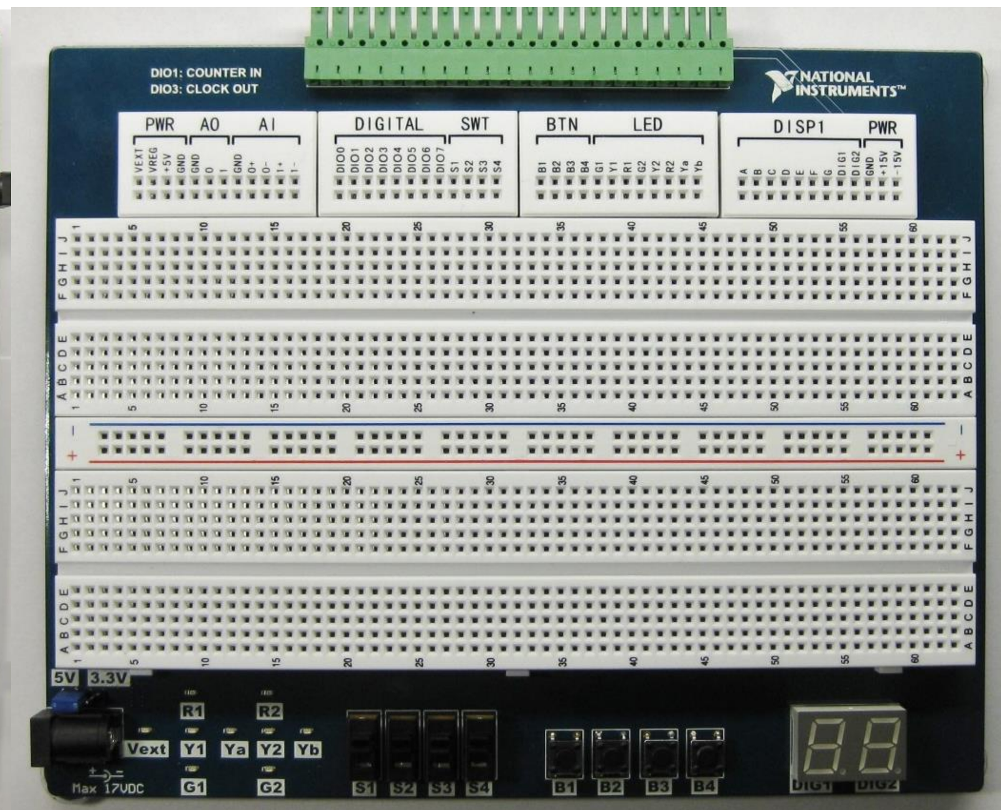




Advanced Breadboards

- Digital design tools that already have common components in place for you. They also sometimes have advanced programming ability to create large circuits.





Why Breadboard?

1) It takes less time (and money) to breadboard a circuit than to design and fabricate a printed circuit board (PCB).

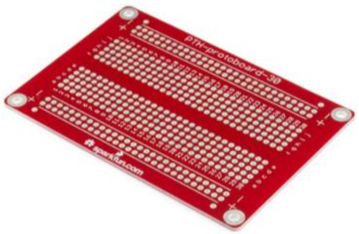
   Because of the cost, a PCB should be reserved for the final working design.

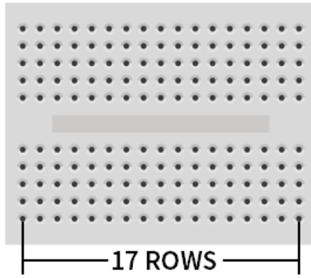
2) As a complement to circuit simulation, breadboarding allows the designer to see how, and if, the actual circuit functions.

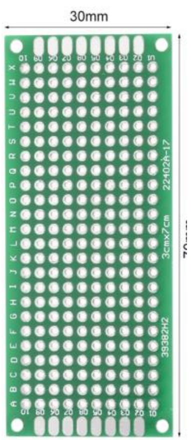
3) Breadboards give the designer the ability to quickly change components during development and testing, such as swapping resistors or capacitors of different values.

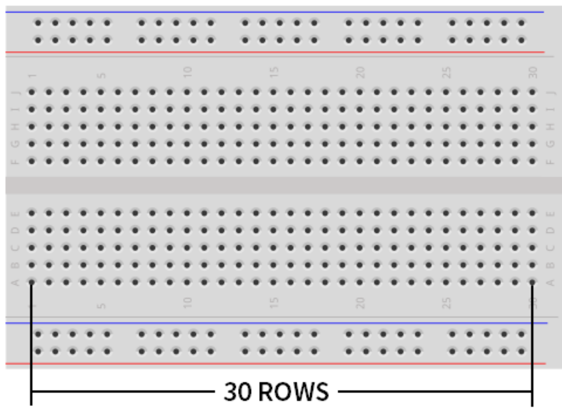
4) A breadboard allows the designer to easily modify a circuit to facilitate measurements of voltage, current, or resistance.

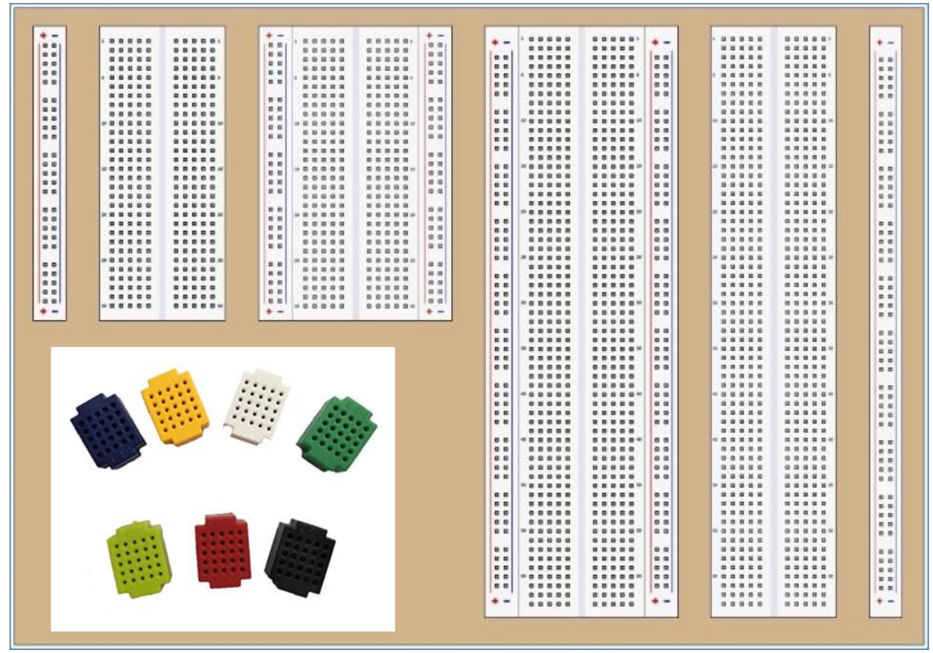
Different Type of Breadboards

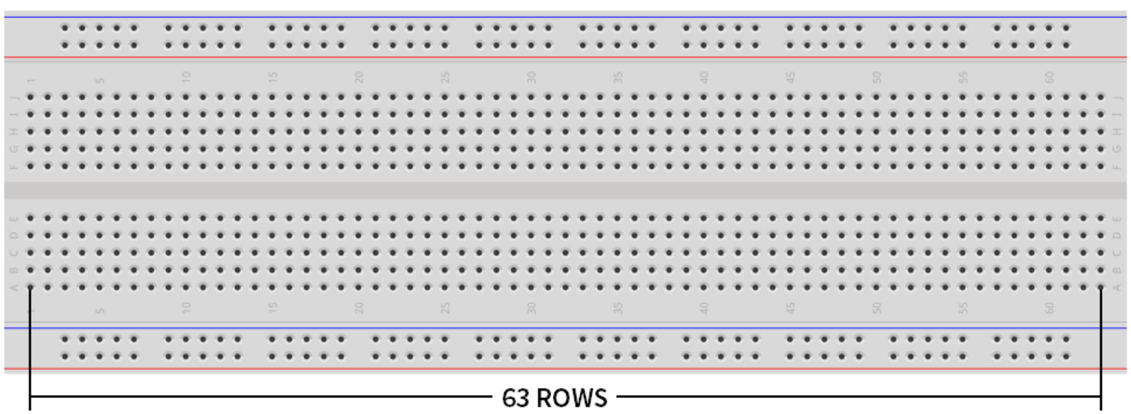




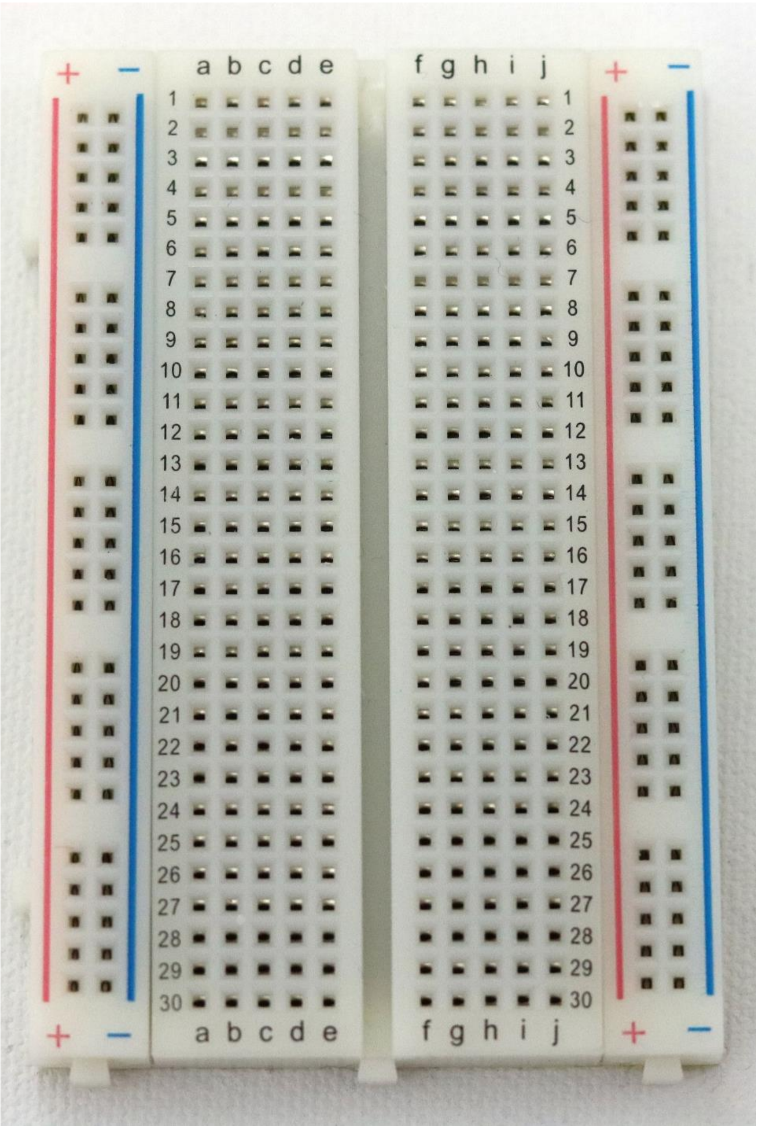


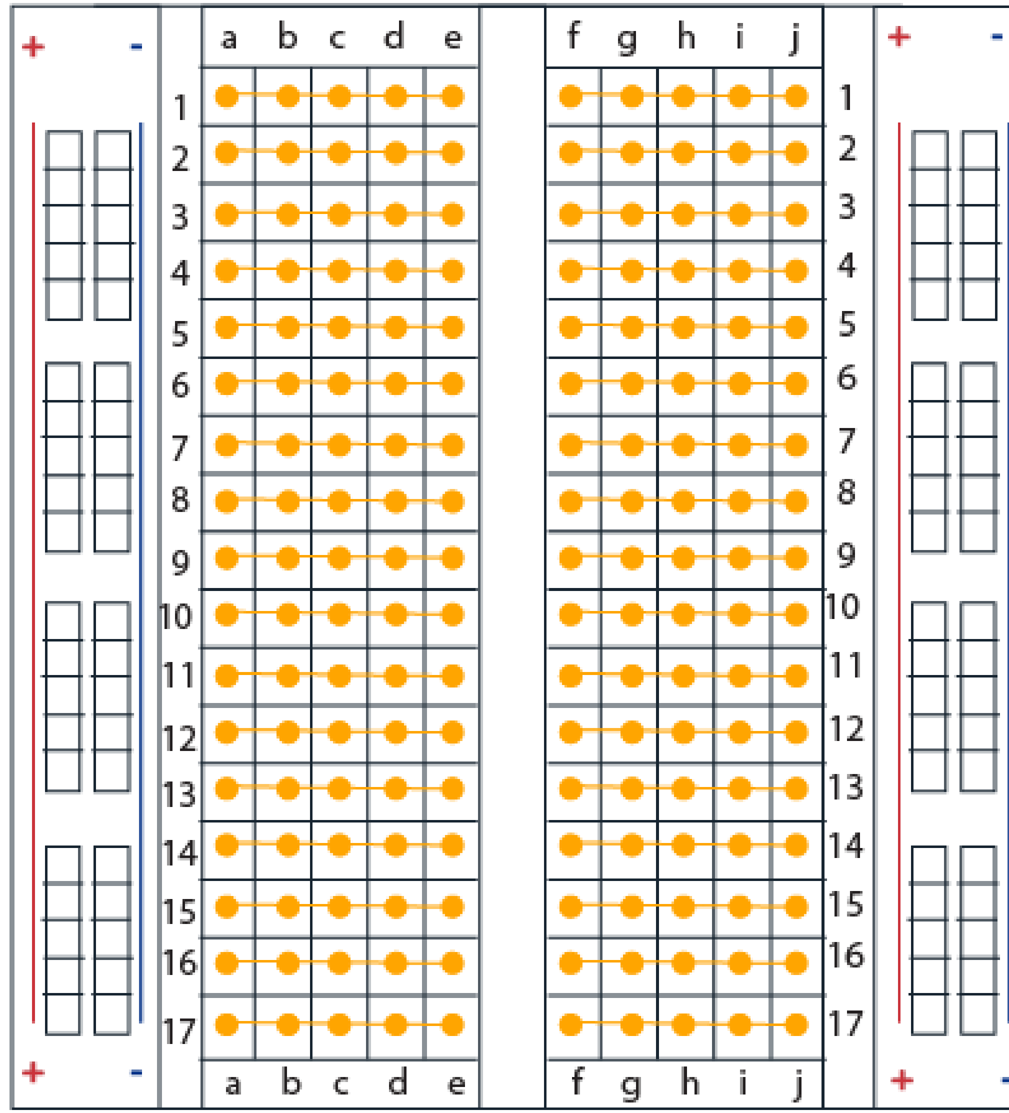




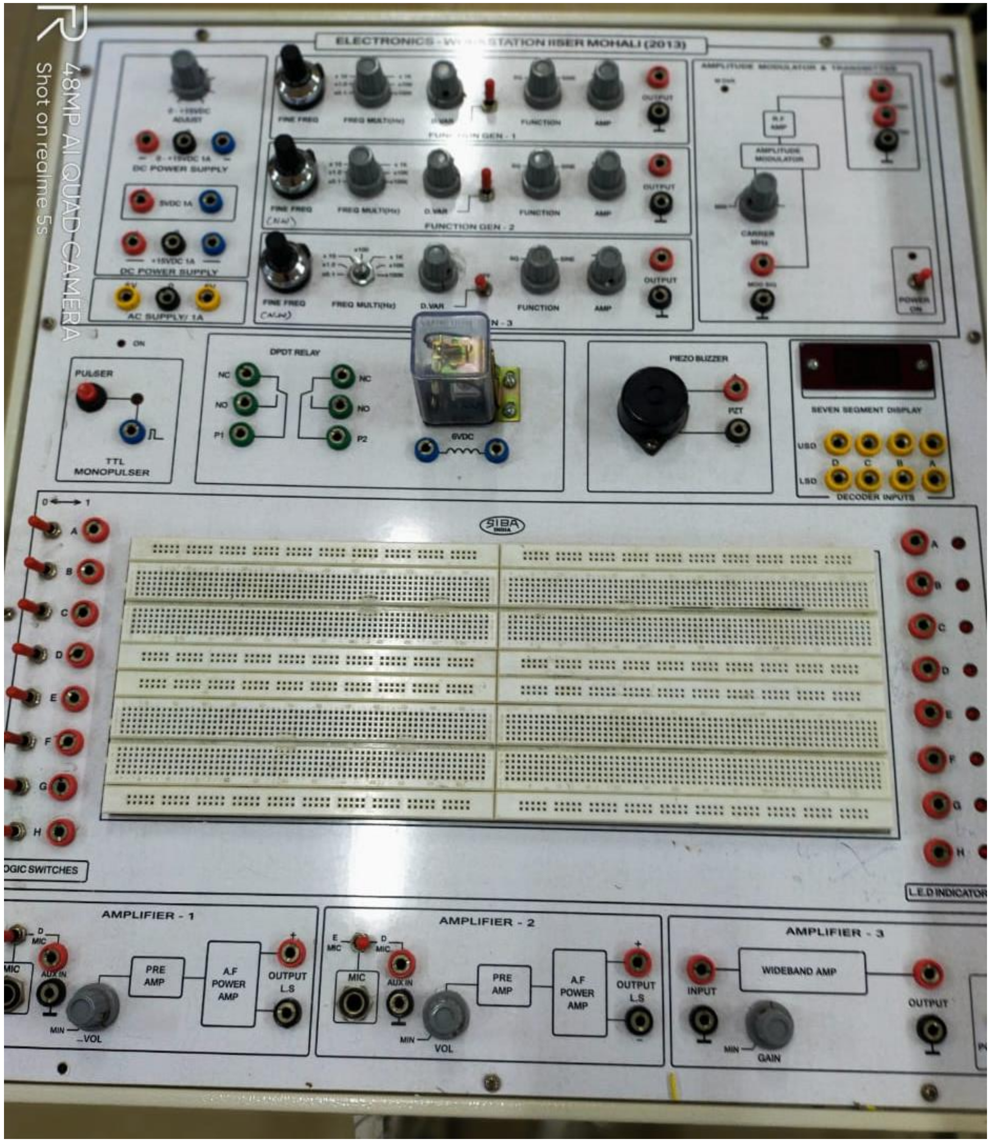


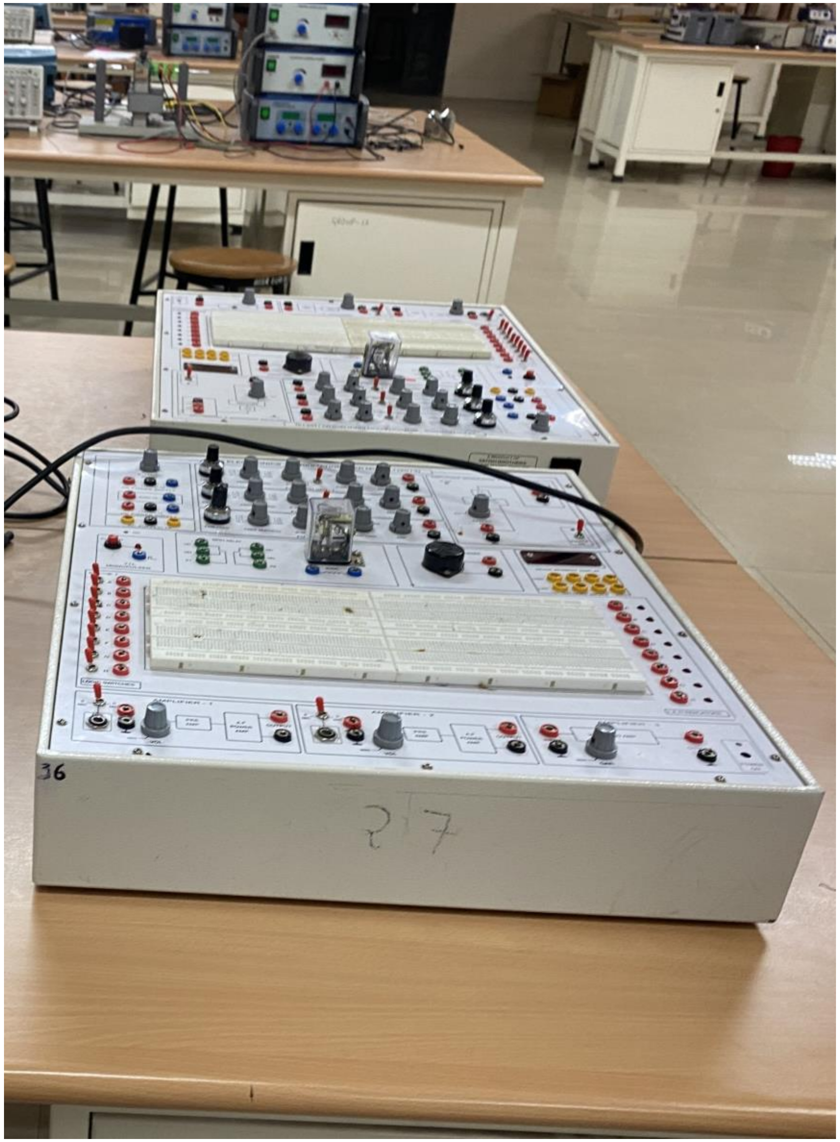
Breadboard in Lab





Customize Breadboard in Lab

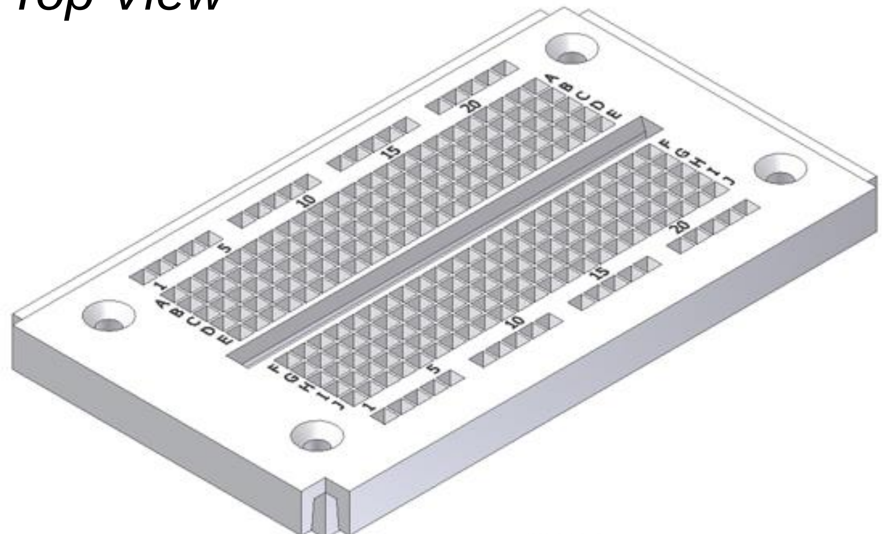




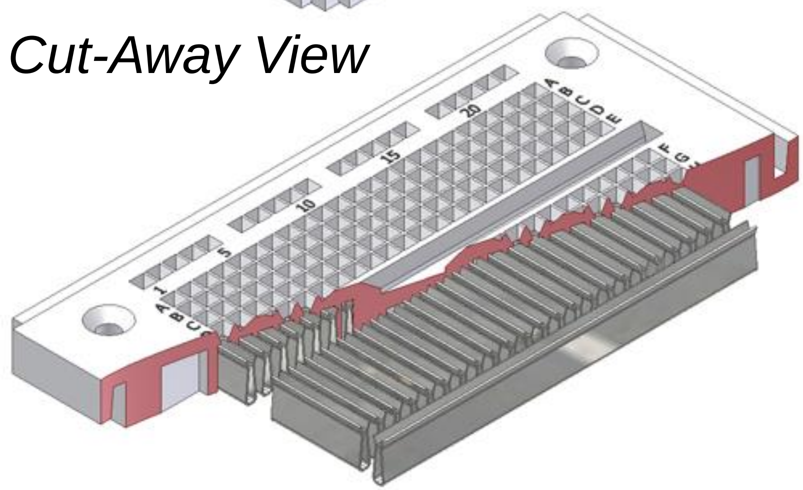
How a Breadboard Works

- Electric component leads and the wire used to connect them are inserted into holes that are arranged in a grid pattern on the surface of the breadboard.
- A series of internal metal strips serve as jumper wires. They connect specific rows of holes.

Top View

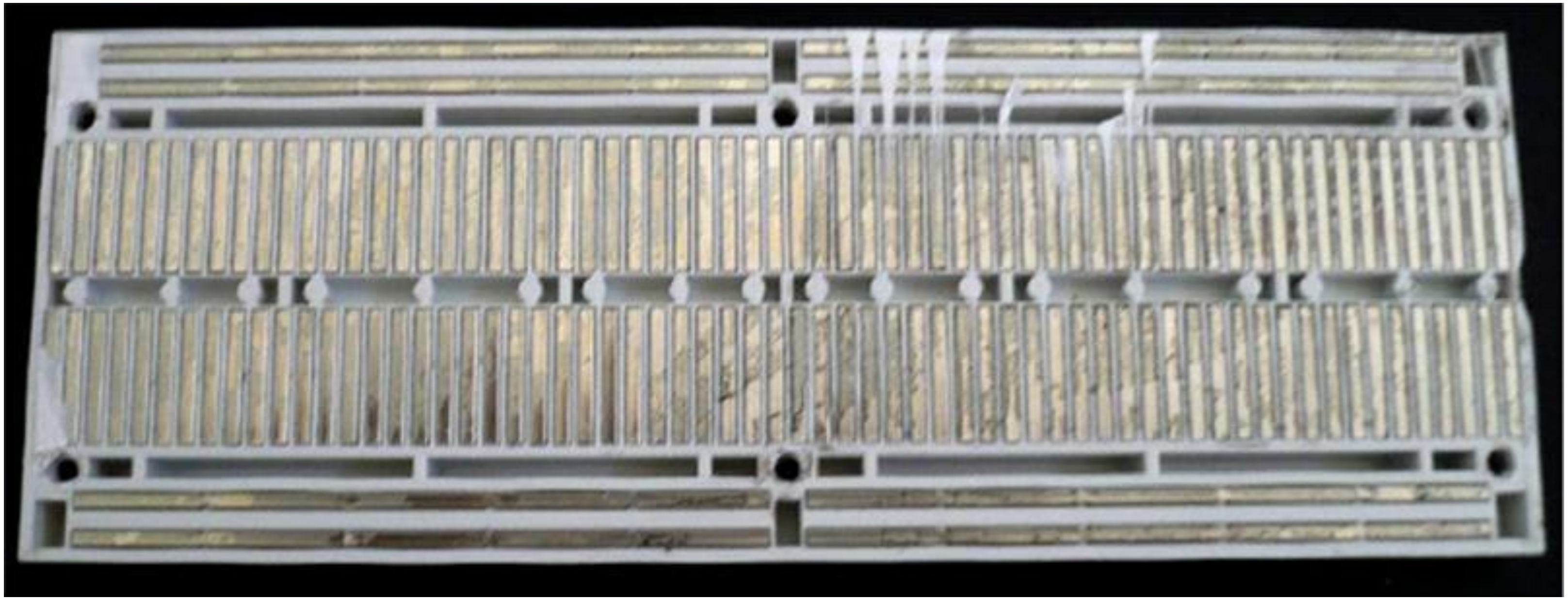


Cut-Away View



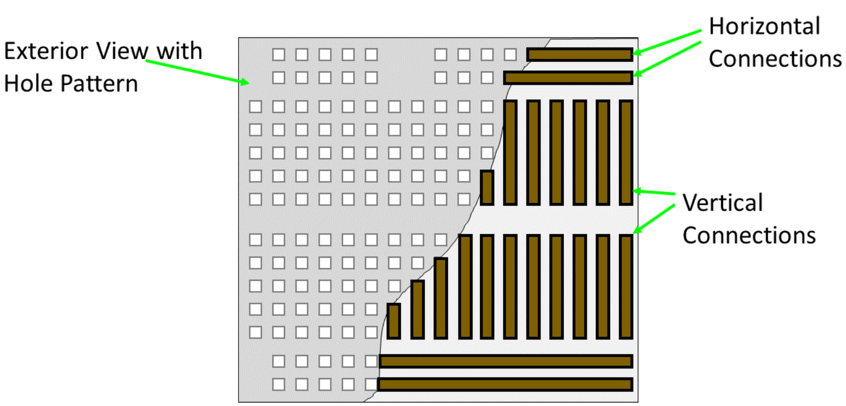
Breadboard: internal connection

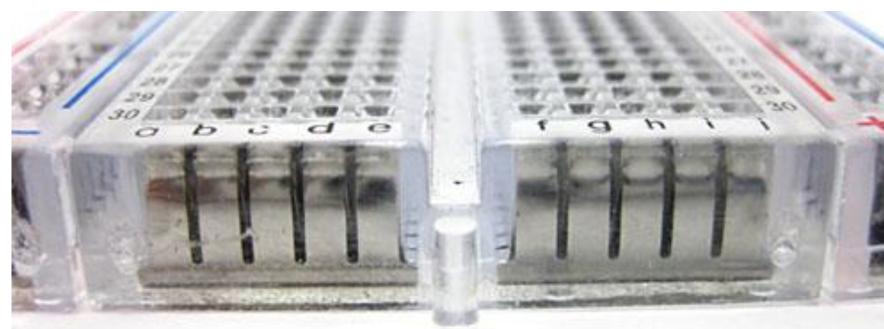
- This is the back surface of the breadboard
  - Some metal strips run horizontally and some run vertically.
    - These strips create a low resistance connection between the sets of square holes along the metal strip to allow you to easily connect ends of components together without running wires between them.
      - Wires are used to make jumpers between metal strips.
        - Maximum frequency of operation is 4 MHz, due to parasitic capacitance



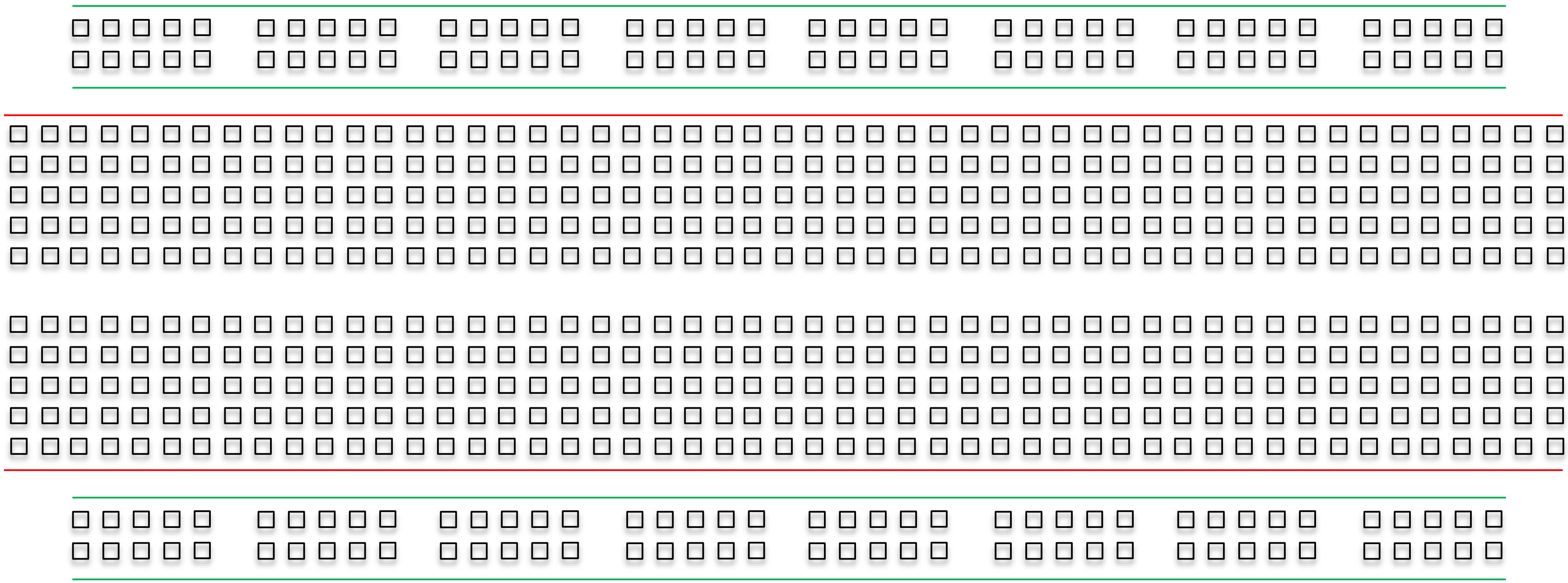
How breadboard is internally connected

Breadboard Internal Wiring





How breadboard is internally connected

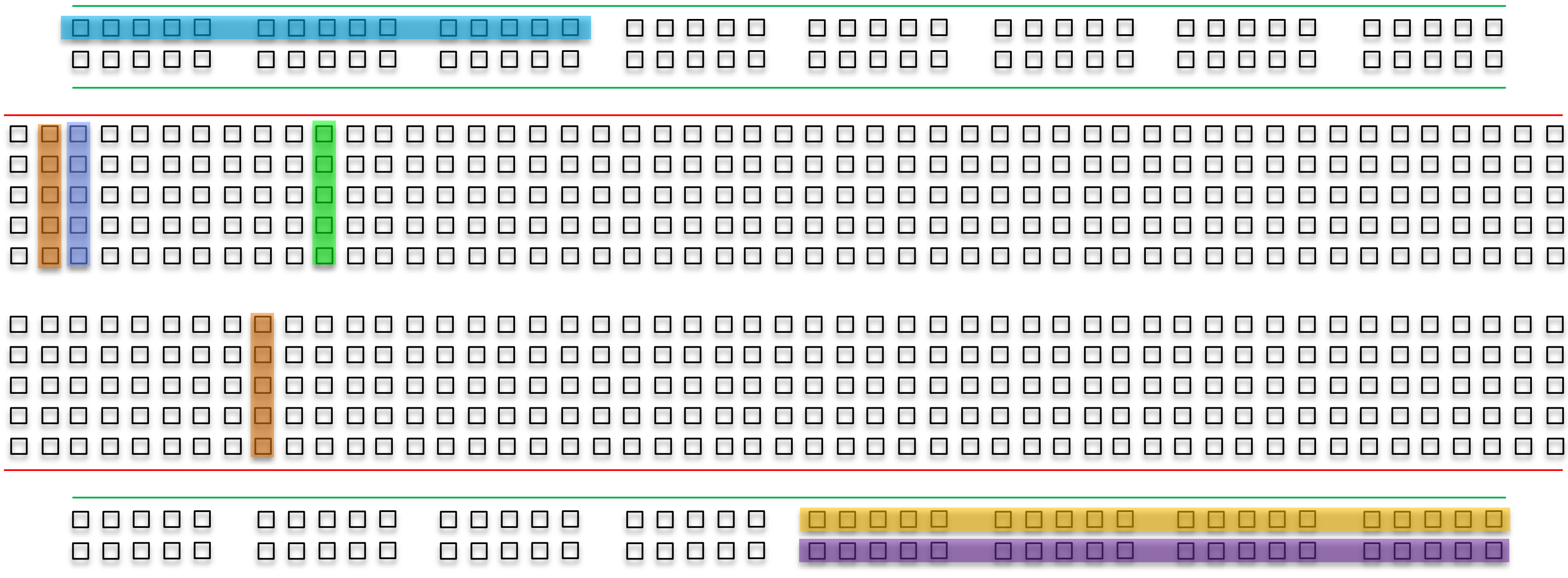


A breadboard consists of two areas called strips and are often separated from the middle portion (commonly known as ravine).

Bus strips are mainly used for power supply connections

Terminal strips are mainly used for electrical components: Each strip consist of 5 pinholes, indicating that you only can connect up to 5 components in one particular section

How breadboard is internally connected



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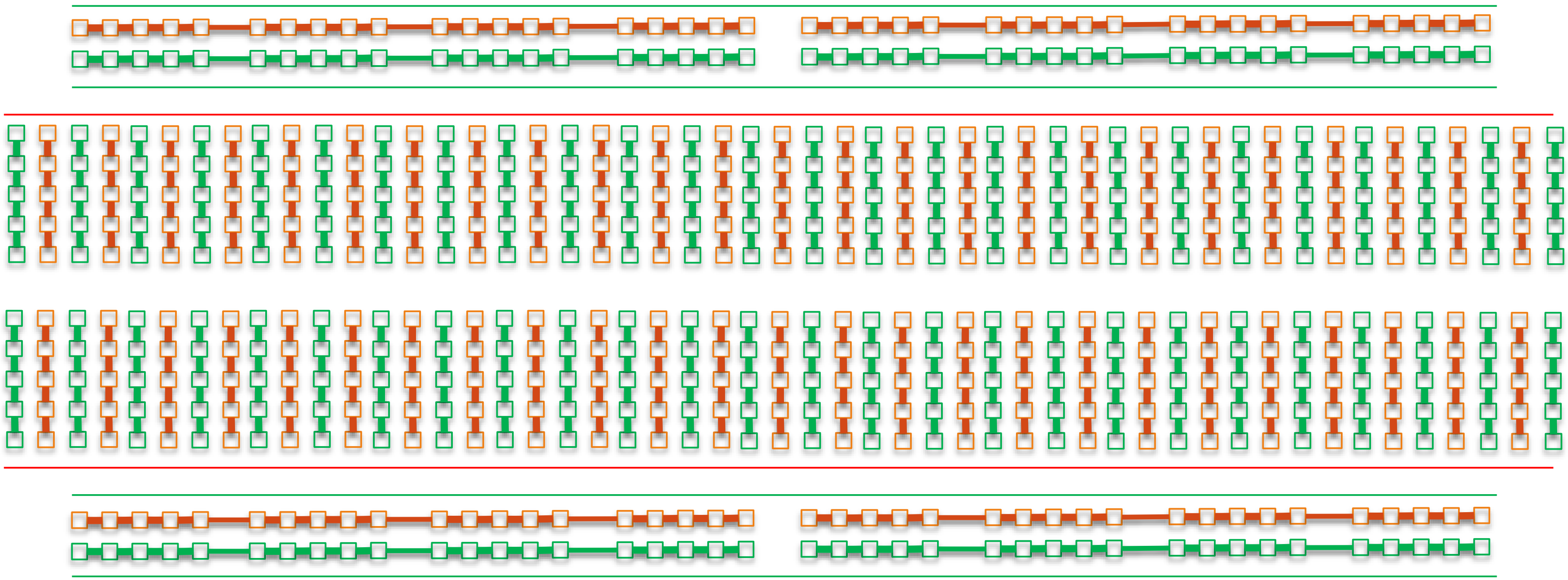

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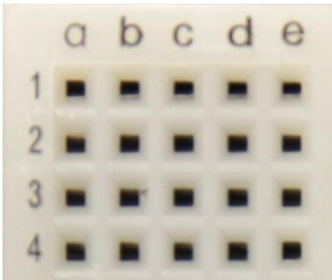
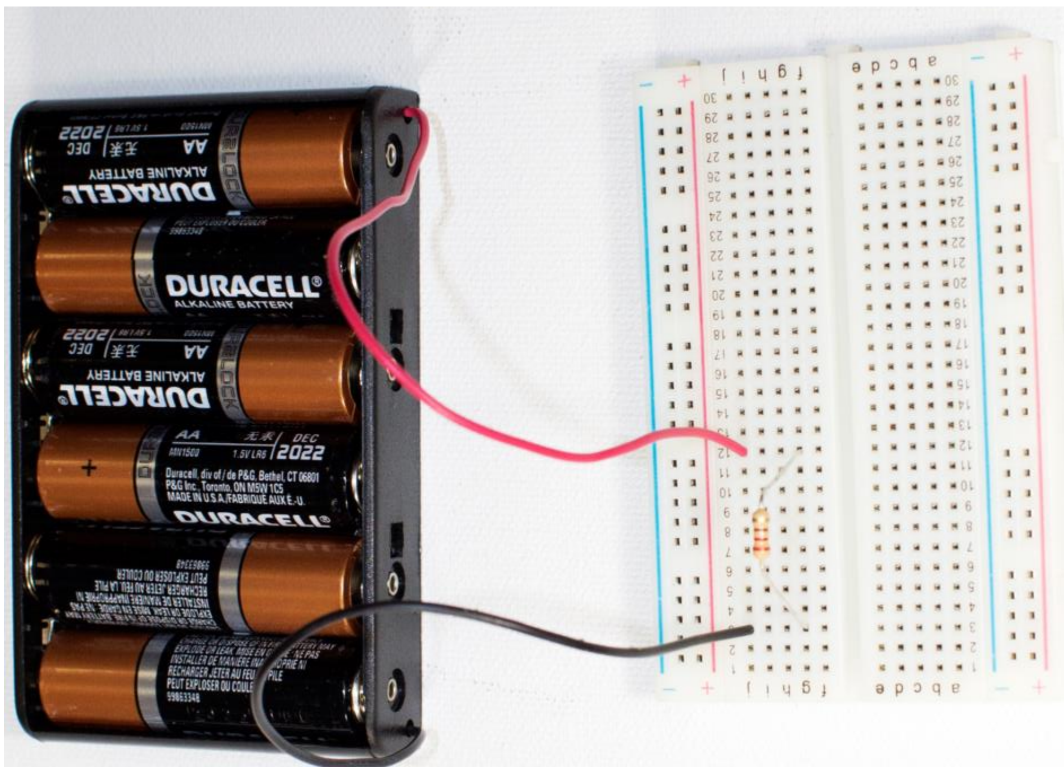
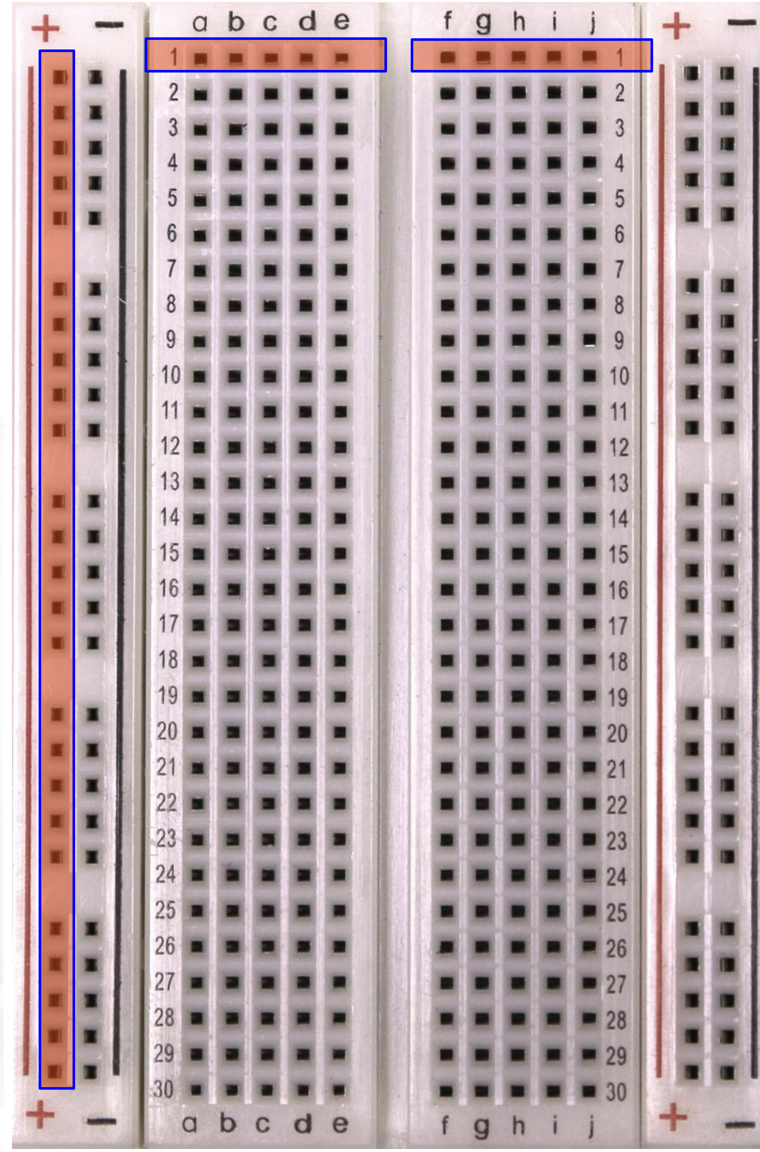
How to use a Breadboard

- Columns and rows connected

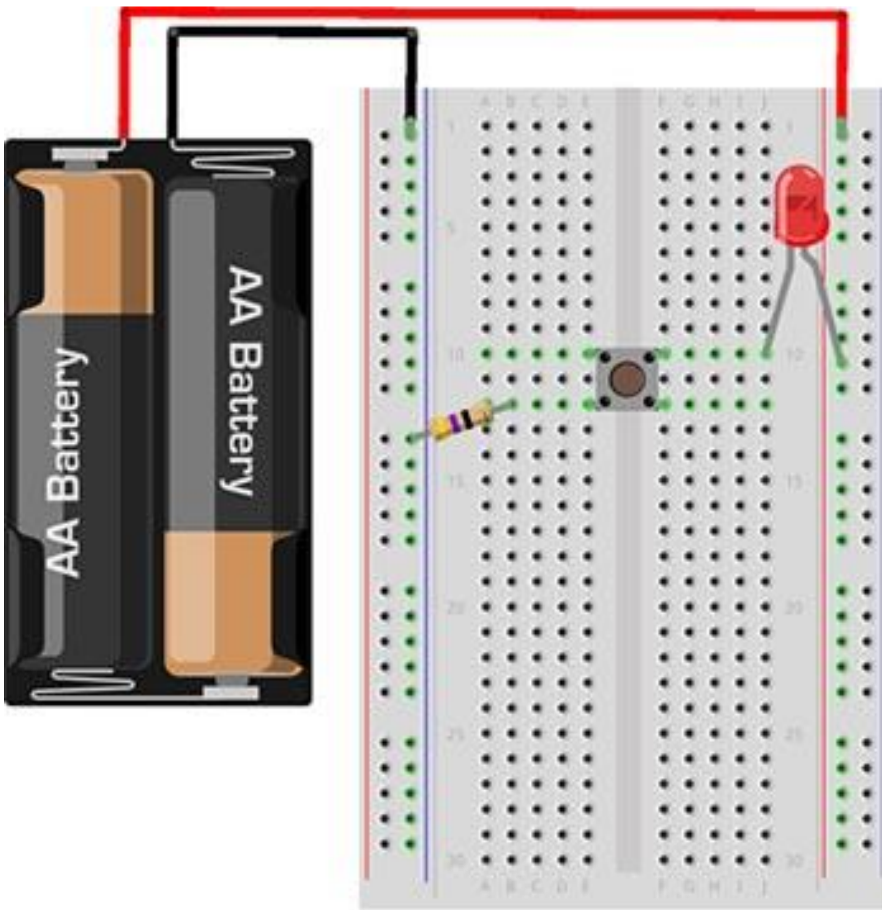


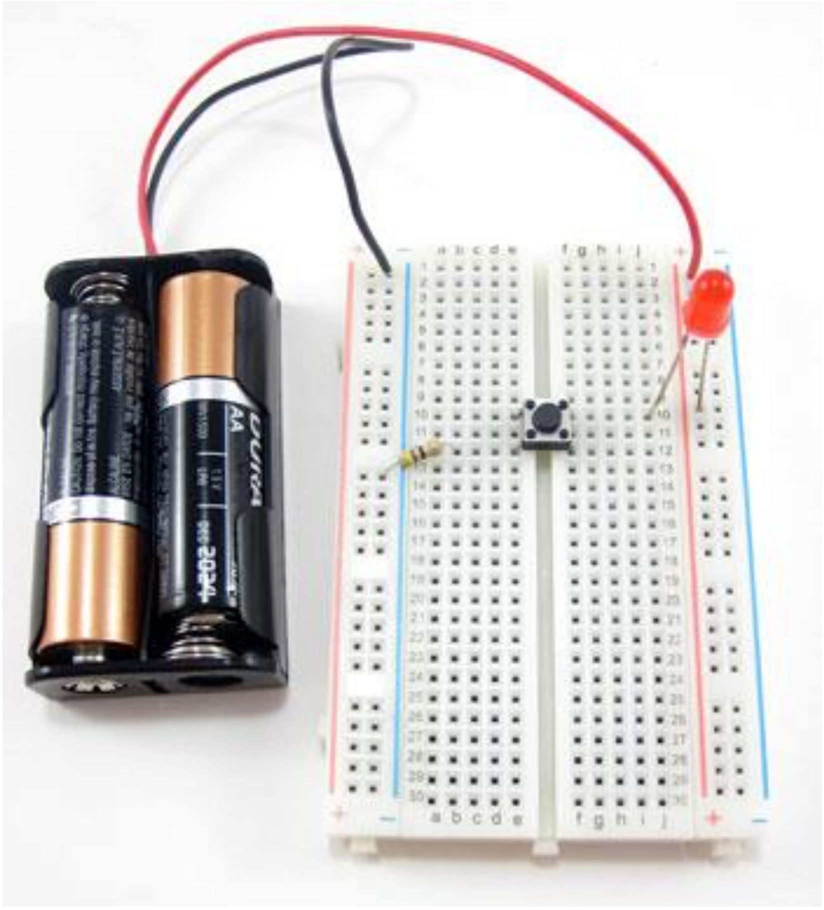
Holes to connect wires



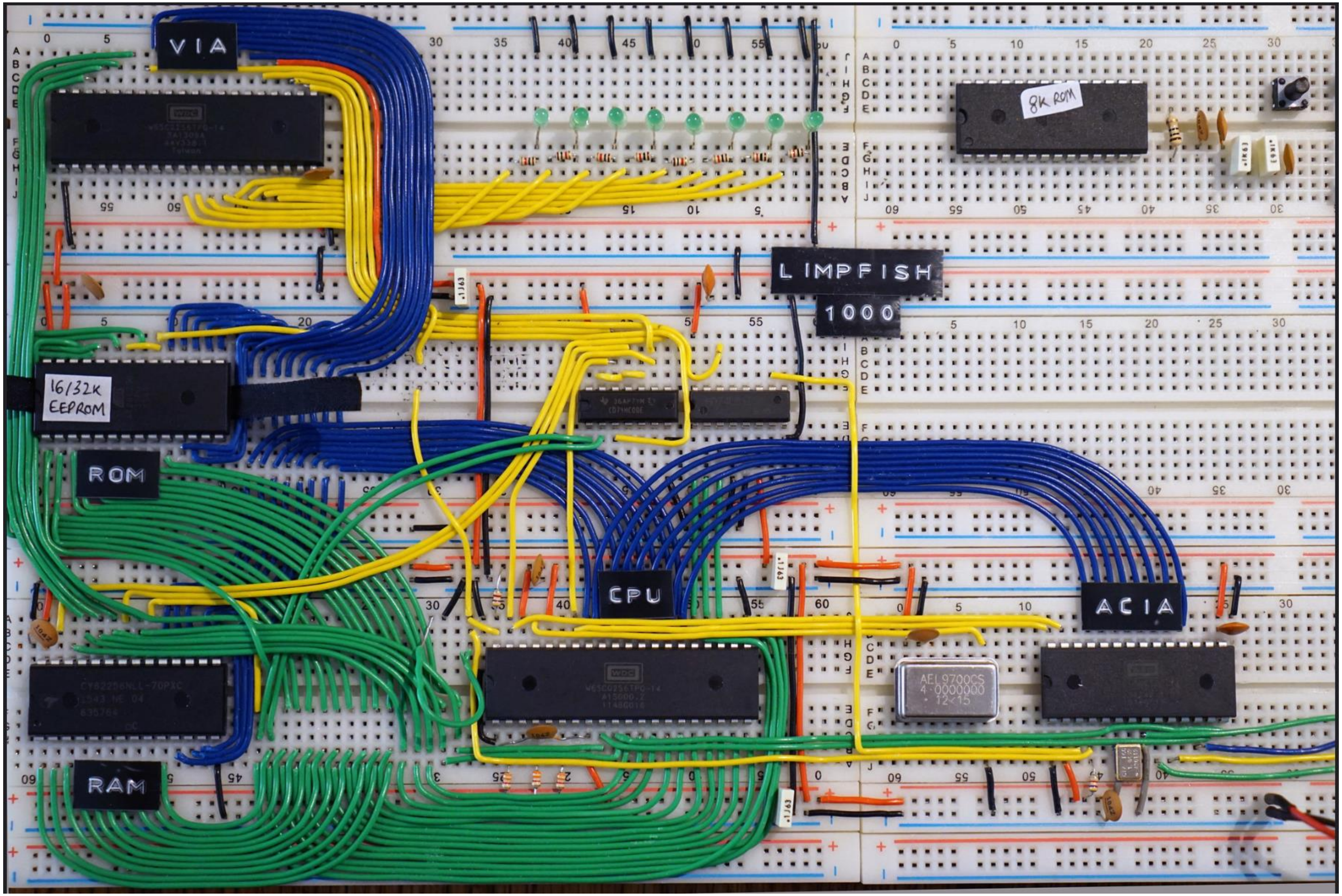


How to use a Breadboard

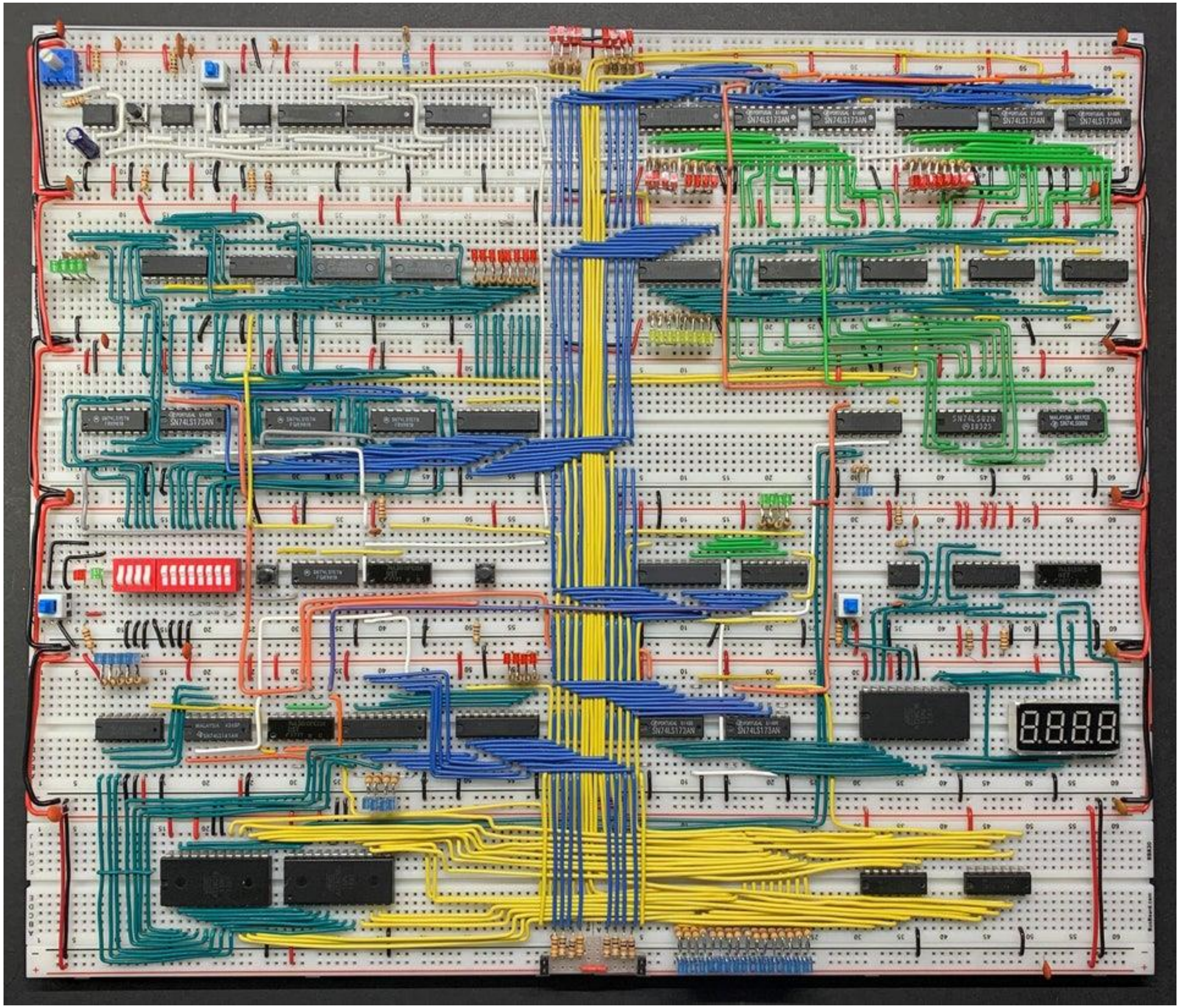




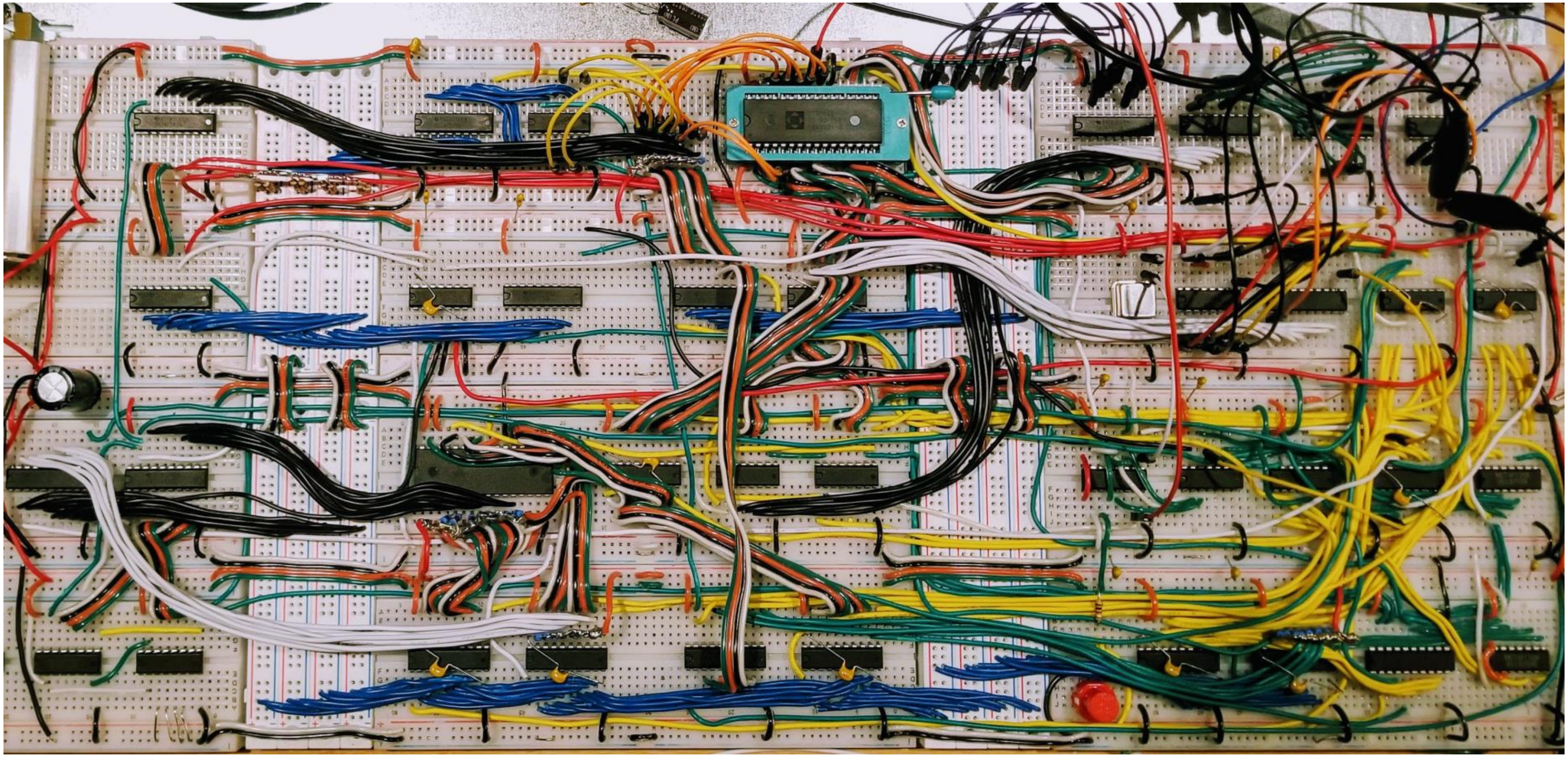
Home made 6502 8bit breadboard computer



8-Bit Computer

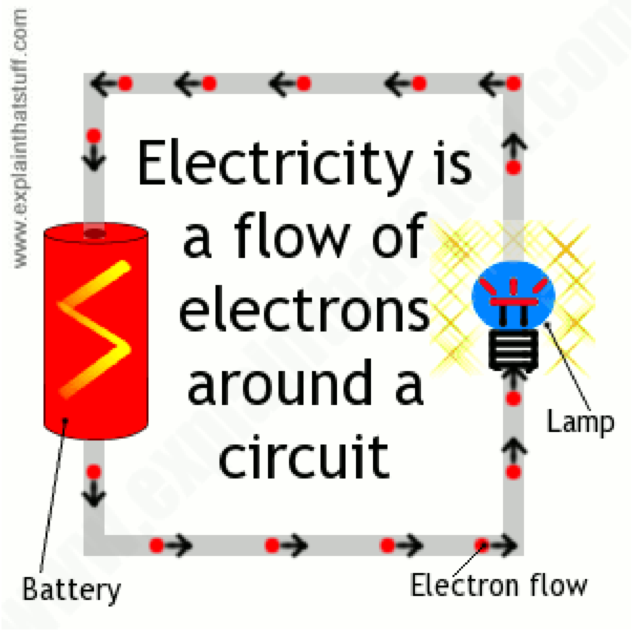


An interesting Project



- The rate of movement of electrons can be measured over a certain amount of time.

- The current is defined as the rate of charge movement or the movement of electrons through an area over a given amount of time.



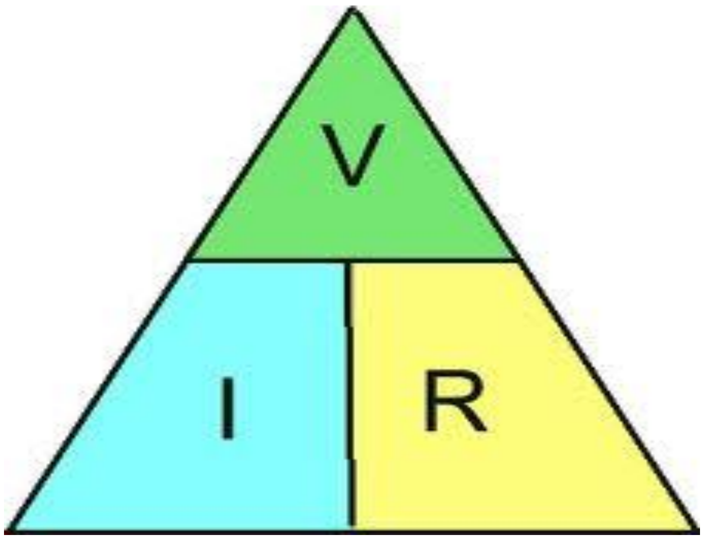
- Remember the Law of Conservation of Energy, which states that energy cannot be created or destroyed, but may only change form. This law applies here as electrical charges can be transferred between objects.

Ohm's Law

- An electron travelling through the wires encounters resistance. **Resistance** is the hindrance to the flow of charge. For an electron it is a zigzag path that results from countless collisions with fixed atoms within the conducting material

- **Voltage = Current x Resistance**
  (Volts) (Amps) (Ohms)

$$V = IR$$

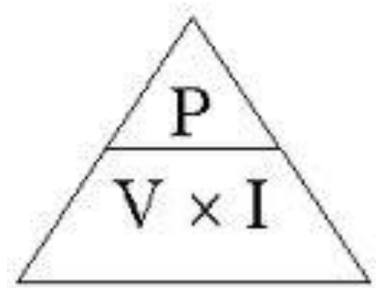


I and V are directly proportional to one another when the resistance stays constant

Power

- Power is the rate of energy used (how quickly you use energy).
- Power = energy / time
- Power is measured in Watts (W)
- 1Watt = 1 joule of energy used every second.

- In electricity we use the equation:
- Power = Voltage x Current
  (Watt) (Volts) (Amps)
- Or use symbols
- P=VI



Electricity that moves…

- How can we control currents?:
  - We need to understand the flow of electricity
  - And a suitable circuit
  - Also, to understand what is the source of electricity or how the electricity is generated

- How to measure these quantities?

Can Magnetism Help?

Magnetism and electricity

- Term comes from the ancient Greek city of Magnesia, at which many natural magnets were found. We now refer to these natural magnets as **lodestones** (also spelled loadstone; lode means to lead or to attract) which contain **magnetite**, a natural magnetic material Fe_3O_4.
- Pliny the Elder (23-79 AD Roman) wrote of a hill near the river Indus that was made entirely of a stone that attracted iron. And the material is known to many other civilization
- Use of magnets to aid in navigation can be traced back to at least the eleventh century.

- William Gilbert coined the term electric, from the Greek elektron, to identify the force that certain substances exert when rubbed against each other.
- The science of electricity has its roots in observation, known in 600 BC that a piece of amber rubbed with animal fur would attract straw, feathers
- Flying a Kite Experiment during a thunderstorm by Benjamin Franklin 1752

Basically, we knew the phenomenon existed and we learned useful applications for it. We just did not understand it. => Not until 1819

- Laws of electricity
  - Oersted showed that magnetic effects could be produced by moving electrical charges; Faraday and Henry showed that electric currents could be produced by moving magnets

- Laws of electricity
  - electric charges produce *electric* fields (Coulomb)
  - electric fields begin and end on charges
- Laws of magnetism
  - currents produce *magnetic* fields (Ampere)
  - magnetic field lines are closed loops
  - a changing magnetic field can produce a current (*induced currents*) (Faraday)
  - A changing electric field can produce a magnetic field (Maxwell)

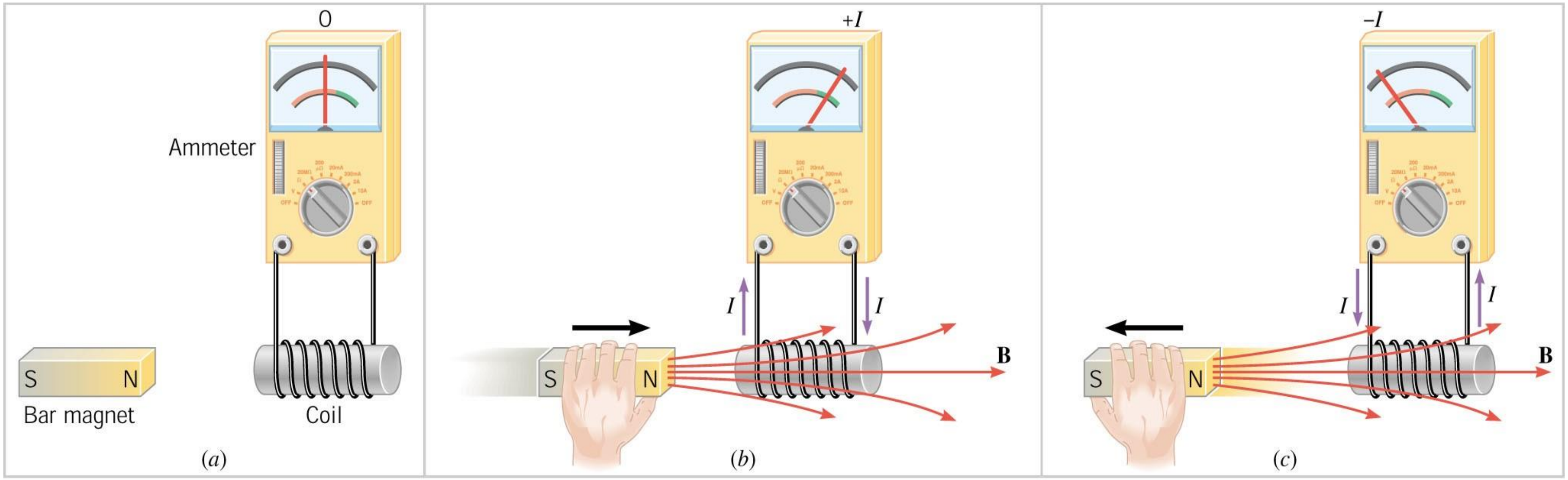
Lesson and path to application

- All magnetic phenomena result from forces between electric charges in motion.

- In 1831, Michael Faraday discovered that a momentary current existed in a circuit when the current in a nearby circuit was started or stopped

- Shortly thereafter, he discovered that motion of a magnet toward or away from a circuit could produce the same effect.

Induced currents



a) No current is induced if the magnet is stationary.
b) When the magnet is pushed toward the coil or pulled away from it, an induced current appears in the coil.
c) The induced current only appears when the magnet is being moved

Electromagnetic Induction

- Electromagnetic induction is when a current is made to flow in a wire.
- This happens when a wire cuts the field lines of a magnetic field and the magnetic field gives the electrons a push. (Voltage). Or the magnetic field changes direction.
- The voltage gives the energy to the electrons to move. This gives the electrons a push, they move, this is an induced current

Induction with Coil and Magnet

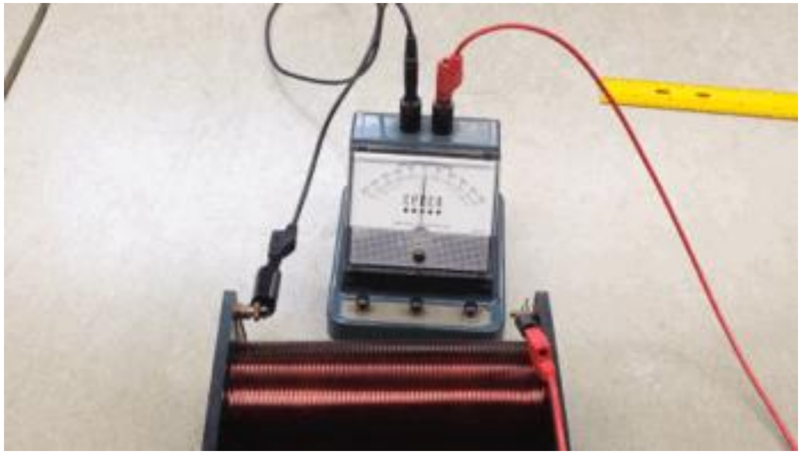
A **changing magnetic field induces** a **current** in a conducting wire

The **magnitude** of this induced electric current depends on **how fast** the magnetic field is **changing**.

Move the **magnet faster** and you get a **larger current**.

Keep the magnet **stationary** and the magnetic field doesn't change at all and you have **zero current**.

Just like the faraday ring, it only conducted as the **current increased** OR **decreased**. So when you close or open the switch. When running it produces a **steady electromagnet** which **does not induce** a PD in the secondary coil



No electrical link

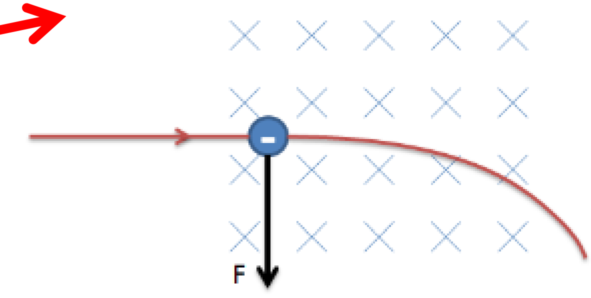
Secondary coil

Primary coil

Understanding EM Induction

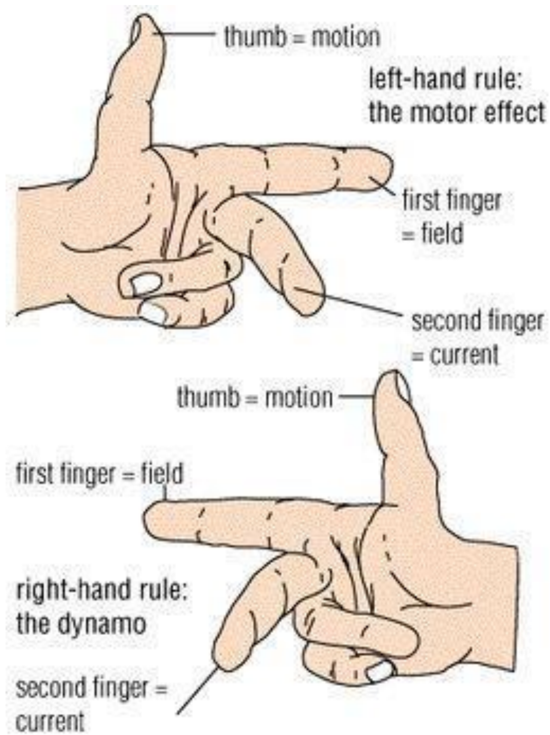
Figure -> Use **LH rule** (as it is moving charges in the field causing motion)

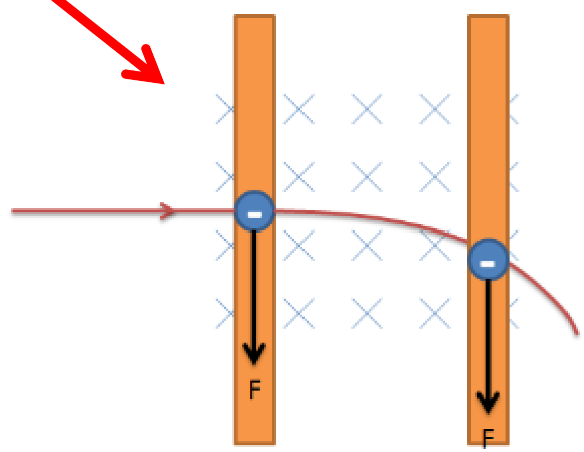
Figure -> Use **RH rule** (as it is you moving an object to create a flow of charges and an induced EMF)



Common misconceptions:
Don't confuse Fleming's left-hand rule (Topic 7.1) with the right-hand rule (Topic 8.1).

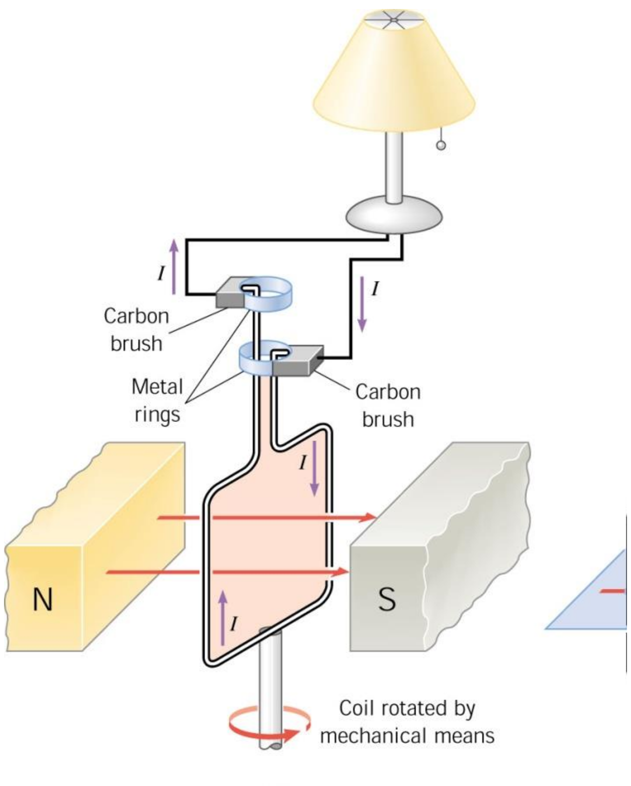
Remembering the phrase '**motors drive on the left**' may help to distinguish the motor rule from the dynamo rule.

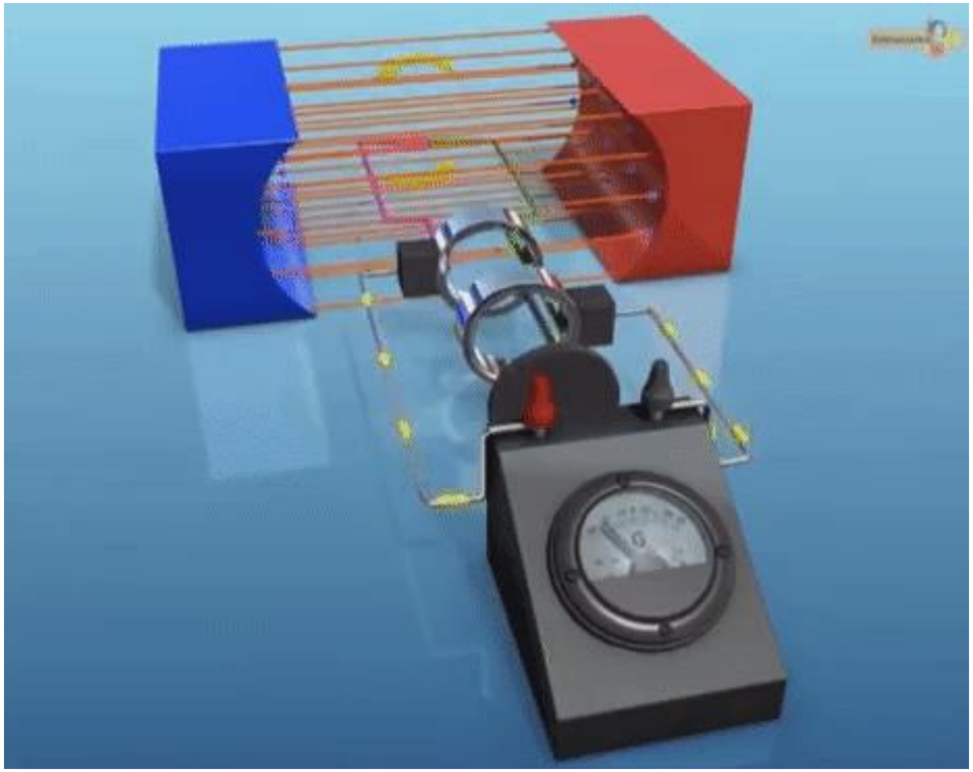




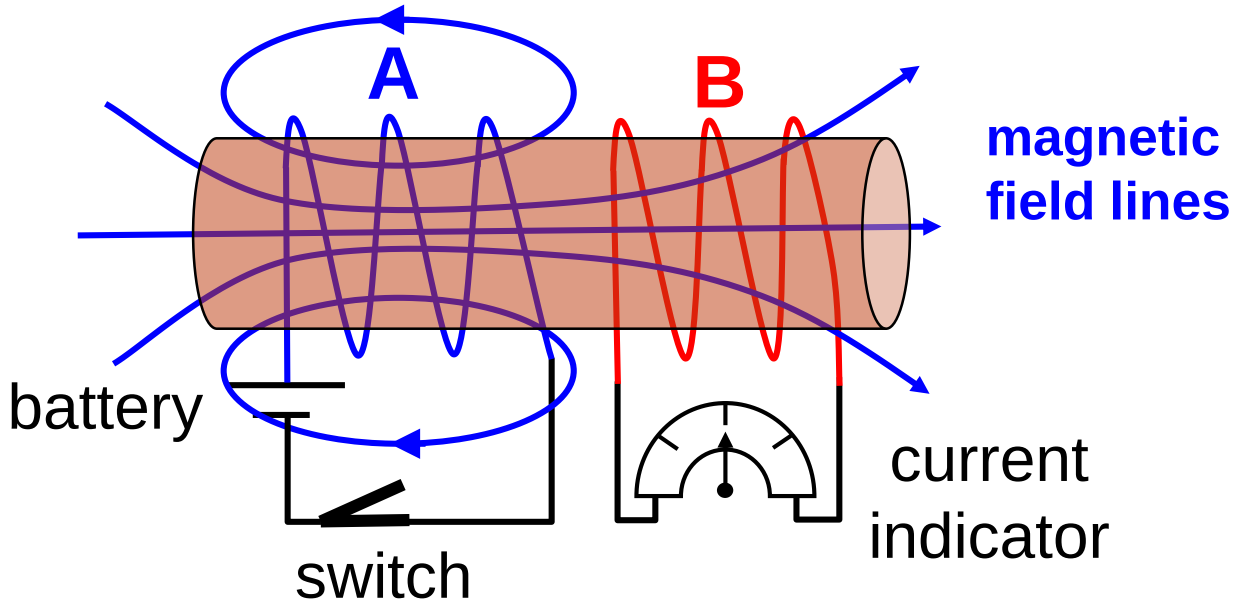
Electric generators

When a coil is rotated in a magnetic field, an induced current appears in it. This is how electricity is generated. Some external source of energy is needed to rotate the turbine which turns the coil.



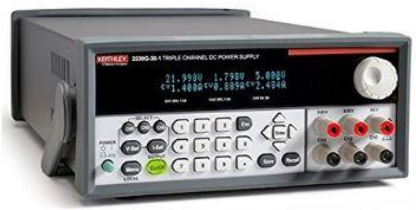


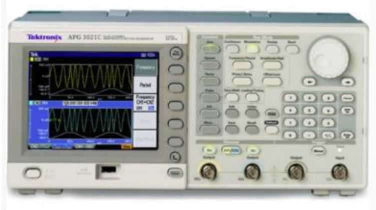
Induced currents

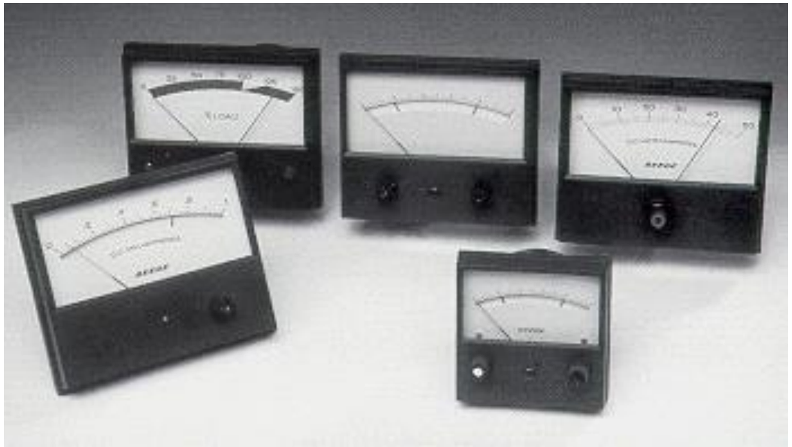


- When a current is turned on or off in coil A, a magnetic field is produced which also passes through coil B.
- A current then **briefly** appears in coil B
- The current in coil B is called an **induced current.**
- The current in B is only present when the current in A is turned on or off, that is, when the current in A is *changing*

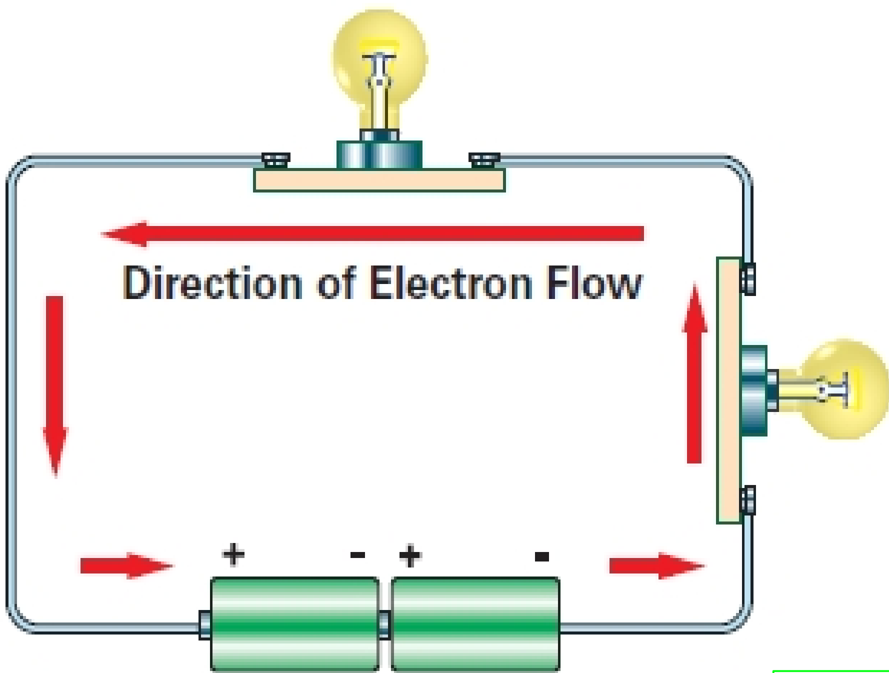
- We need to understand the instrument/device which measures the magnitude of an electrical quantity at the time when it is being measured







Measuring Device: what to measure?



Series Circuit

We know that a circuit is established when there is a continuous path for electricity to travel from one end of the energy source to the other end.

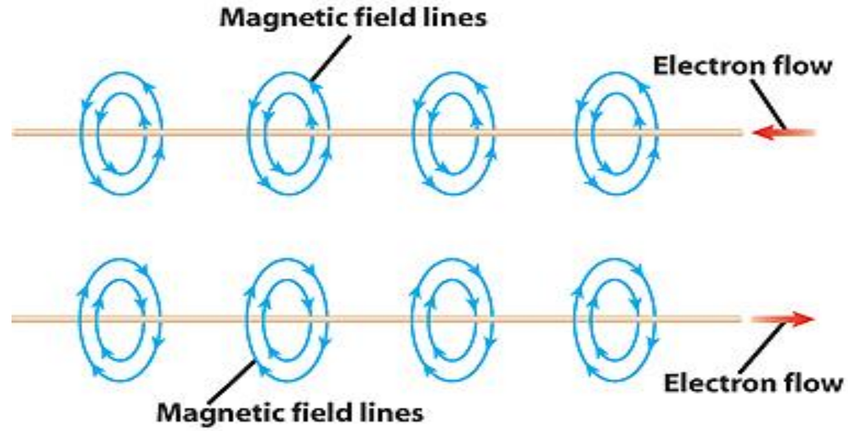
All circuits need three basic parts: an energy source, wires, and the object that is going to change the electrical energy into another form of energy (load).

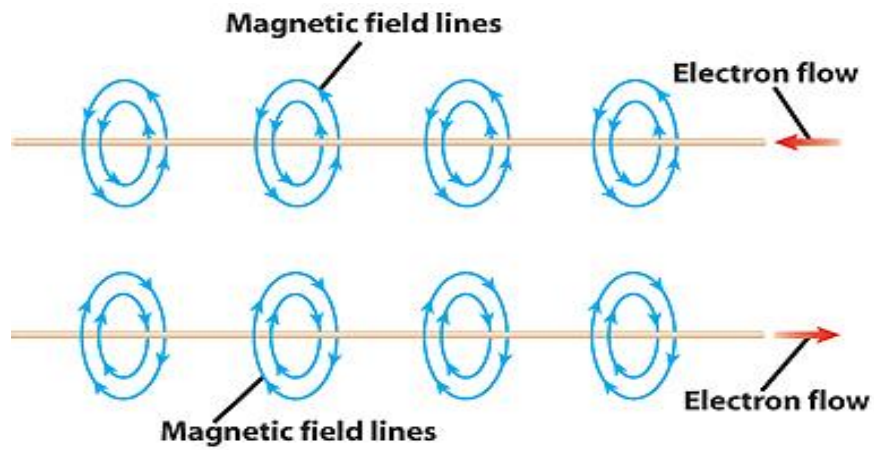
We need to quantify the strength of source (like voltage)
We need to know the flow of current (measuring current)
We need to know what is the amount of power consume
We need to know what is the opposition force (resistance)

We need the devices for these quantities to measure
How do we measure them?

Moving Charges

- Moving charges, like those in an electric current, produce magnetic fields.
  - The magnetic field around a current-carrying wire forms a circular pattern around the wire
  - The direction of the field depends on the direction of the current.
  - The strength of the magnetic field depends on the amount of current flowing in the wire.

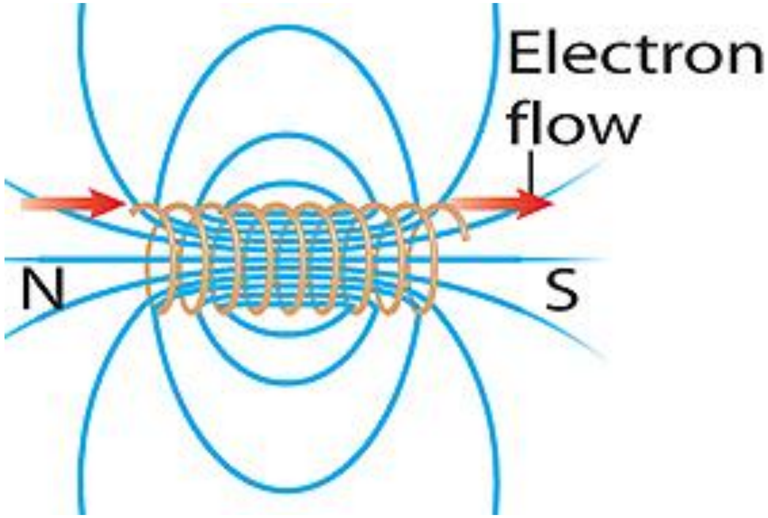


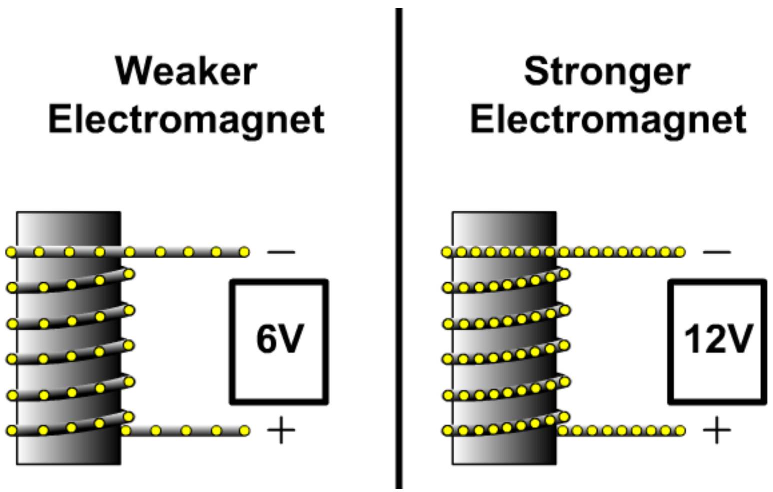


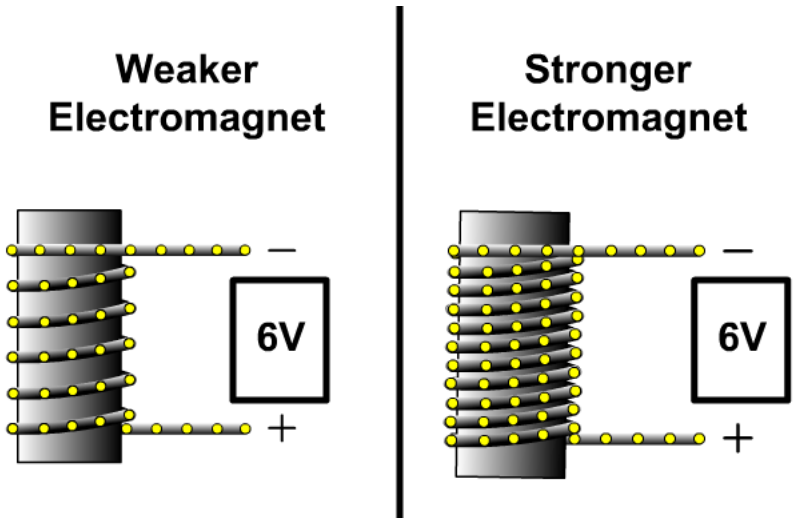
Question is what is the strength and how to determine the direction?

Electromagnet

- Increase strength of the magnetic field by adding more turns to the wire coil or increasing the current passing through the wire.

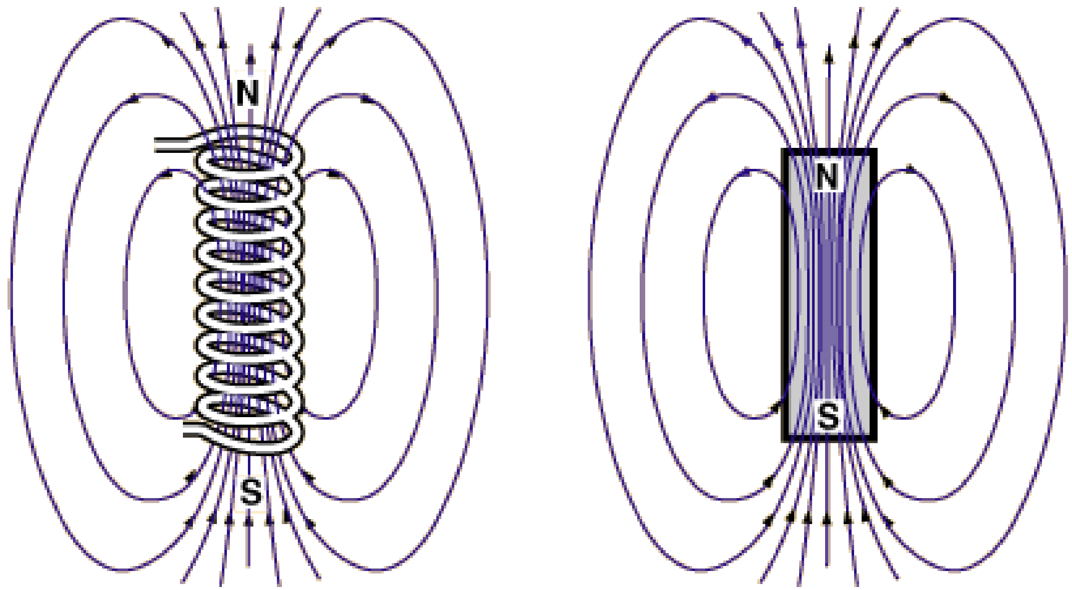


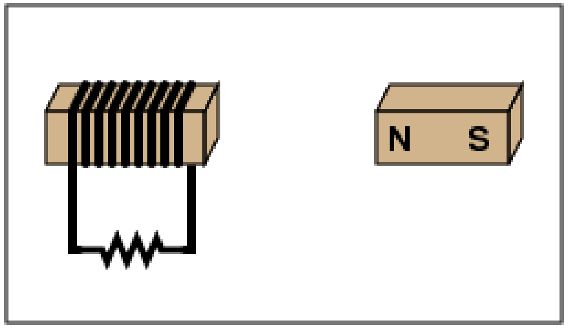




Magnet and Electromagnet

The magnetic field of a coil is identical to the field of a disk-shaped permanent magnet.





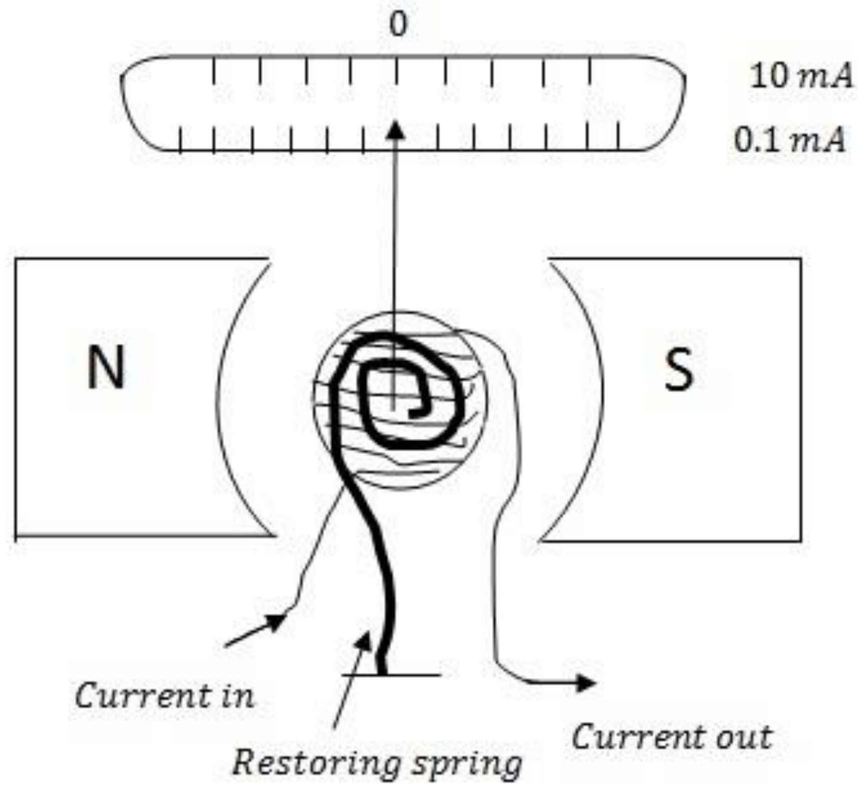
A stationary magnet can push or pull on the assembly of this electromagnet.

Larger field will have large push or pull, how you get larger field? => give more current or more voltage to have more current.

Let's use these concept to build something to measure

Let's make a device

A wire can be wrapped around a piece of iron, and placed between two magnets whereby opposite ends of the magnets face each other. The ends of the wire can be connected to terminals of power



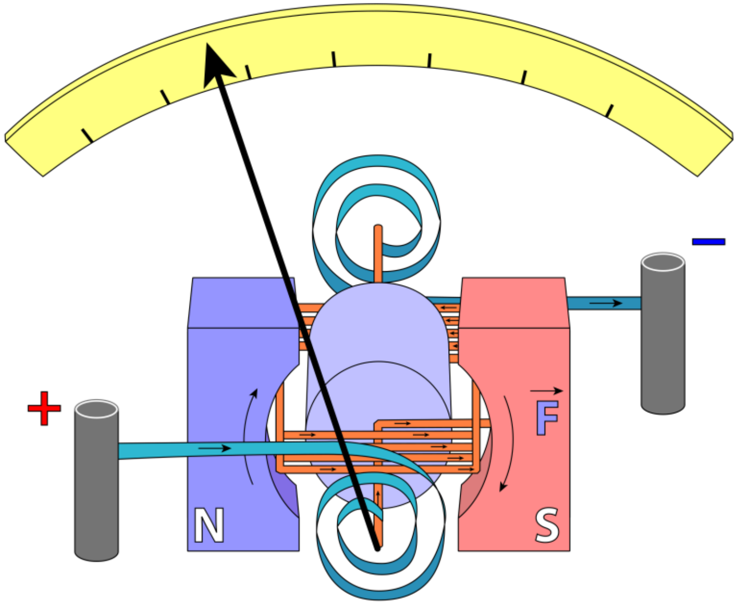
When electric current passes through the coil, a torque is applied to the wire-wrapped core twisting it.

The amount of twisting is proportional to the current through the wire. The needle stops when the torque due to the electromagnetic force is equal to the torque provided by the spring. When the current is turned off, the spring returns the needle to 0.

This was the exact idea of Galvanometer

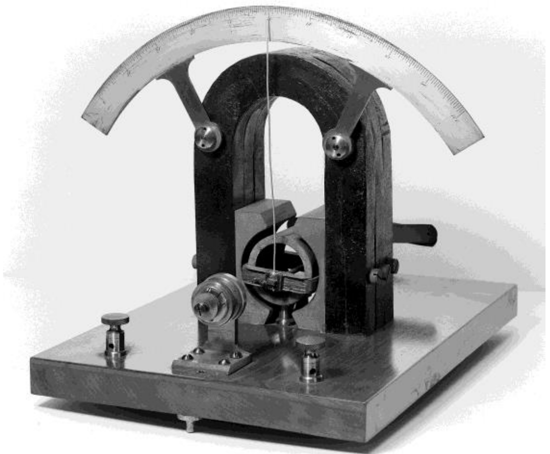
Galvanometer

- **Galvanometer:** a device that uses an electromagnet to measure electric current.
- Galvanometers were the first instruments used to determine the presence, direction, and strength of an electric current in a conductor.



Central Scientific Tangent Galvanometer utilizing compass (1941)

Thomson mirror galvanometer, patented in 1858.



D'Arsonval galvanometer

Galvanometer

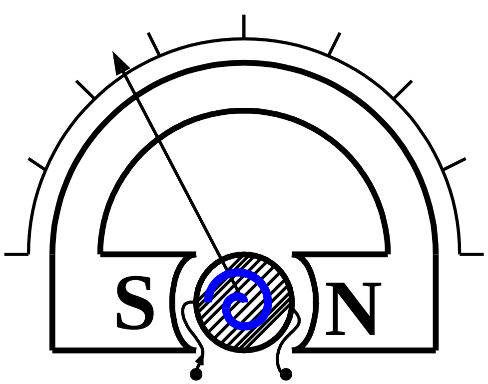
André-Marie Ampère, (1775-1836), is credited with the invention of the galvanometer in 1824. The earliest galvanometers were literally constructed of a compass surrounded by a coil of wire => called *tangent* galvanometers

The early moving-magnet form of galvanometer had the disadvantage that it was affected by any magnets or iron masses near it, and its deflection was not linearly proportional to the current. In 1882 Jacques-Arsène d'Arsonval and Marcel Deprez developed a form with a stationary permanent magnet and a moving coil of wire,

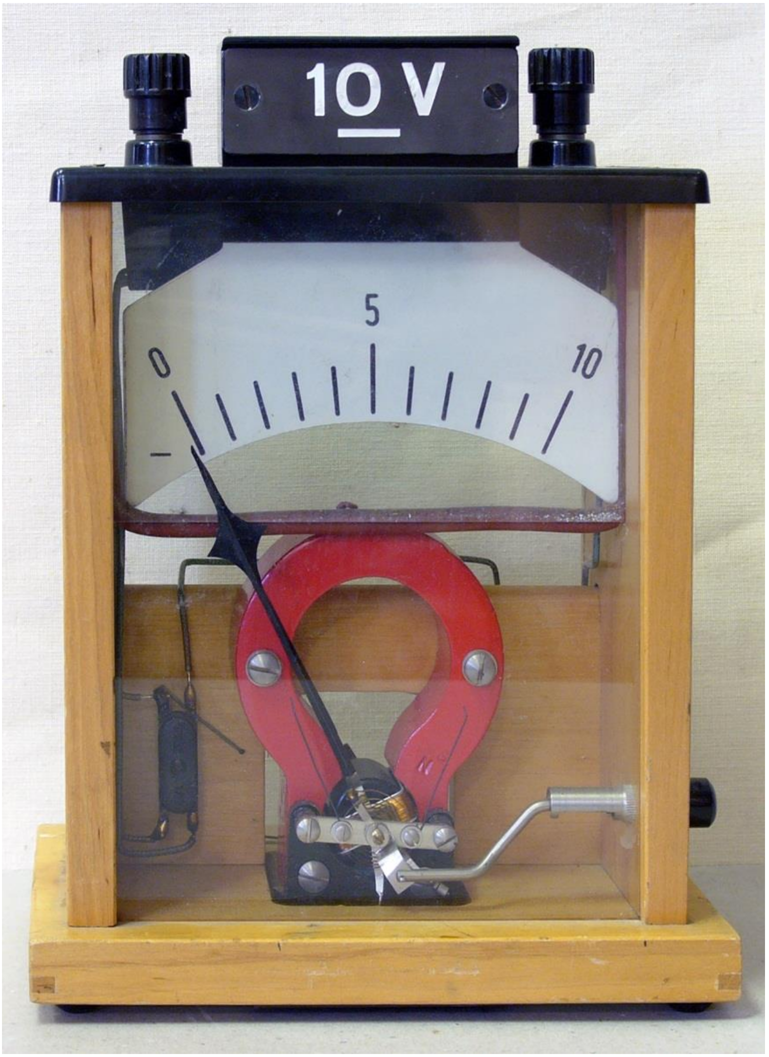
Source: wiki

D'Arsonval Meter Movement

- Permanent Magnet Frame
- Torque on rotor proportional to coil current
- Restraint spring opposes electric torque
- Angular deflection of indicator proportional to rotor coil current



Let's see how the measuring is done



A D'Arsonval Voltmeter

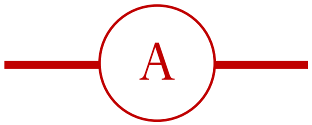
Measuring Devices

When we measure **voltage** or **current** in a circuit, we want to make sure to minimize an effect that our tool has on the circuit so that we get the most accurate results

Ammeter: measures current I

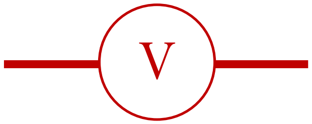
Voltmeter: measures voltage difference ΔV

Ohmmeter: measures resistance R

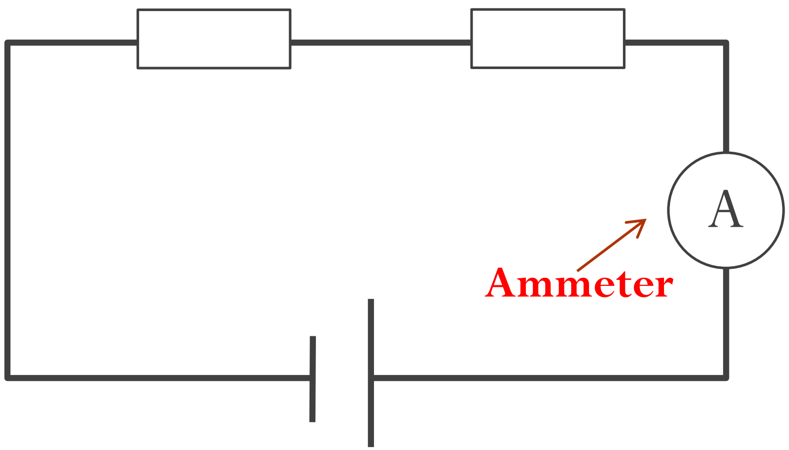


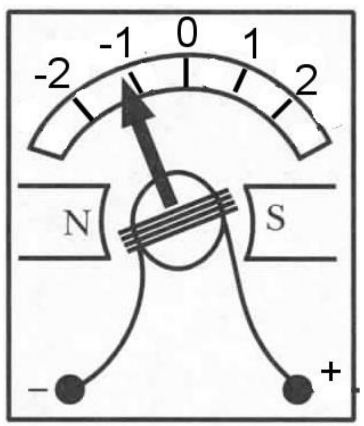
Ammeter

Voltmeter



- Ammeters, Hooked up in **series** with the component being measured

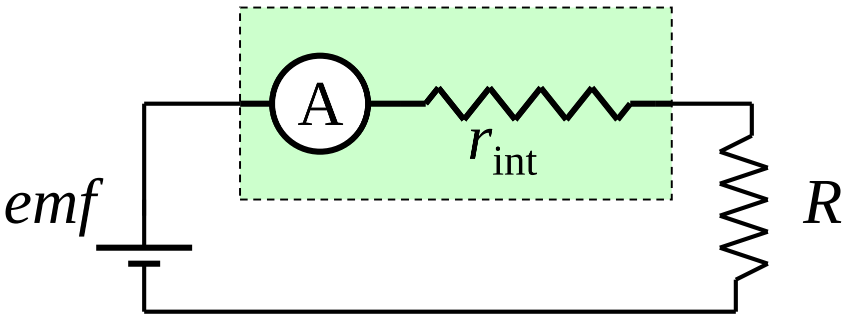




Simple commercial ammeter

Ammeter Design

Ammeter is inserted in series into a circuit – measured current flows through it.



Process of measuring requires charges to do some work:
Internal resistance

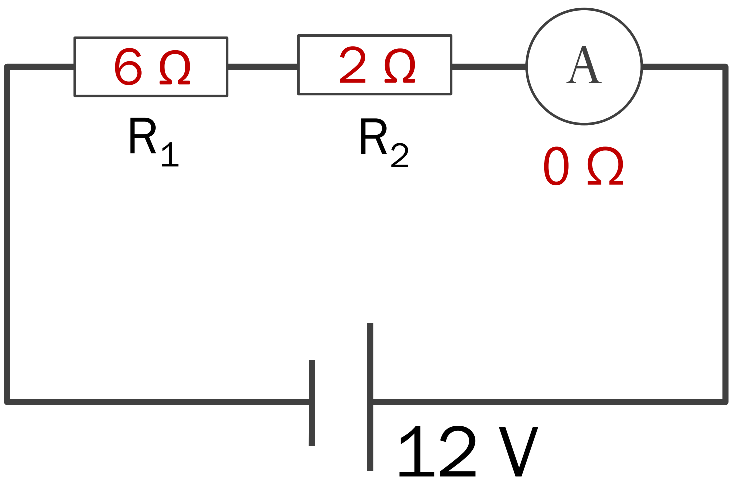
No ammeter: $emf - RI = 0 \longrightarrow I = \dfrac{emf}{R}$

With ammeter: $emf - r_{int}I - RI = 0 \longrightarrow I = \dfrac{emf}{R + r_{int}}$

Internal resistance of an ammeter must be very small

Measuring Current: Ideal Situation =

What is the reading for the current flowing through this ideal ammeter?



$$R_T = 8\ \Omega$$

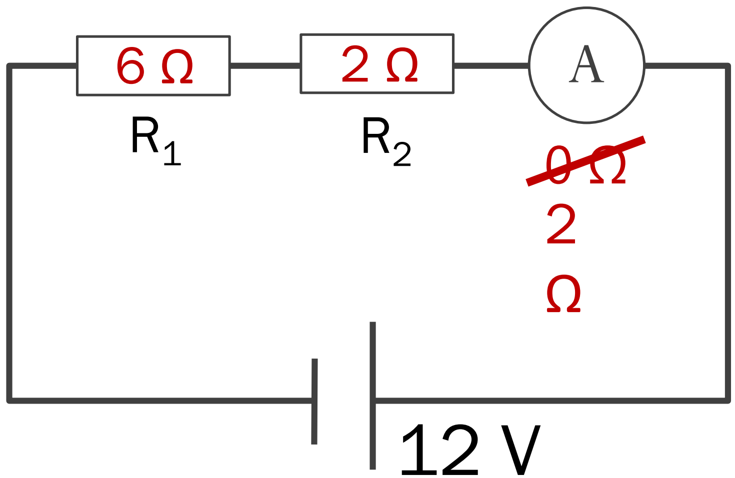
$$I = \frac{V}{R} = \frac{12}{8} = \mathbf{1.5\ A}$$

The ammeter has no effect on the current that it's measuring

An ideal Ammeter will have ZERO resistance

What if Ammeter isn't ideal?

What is the reading for the current flowing through this ~~ideal~~ 2 Ω ammeter?



$$R_T = \cancel{8\,\Omega}\; 10\,\Omega$$

$$I = \frac{V}{R} = \frac{12}{\cancel{8}\; 10} = \cancel{\mathbf{1.5\,A}}\; \mathbf{1.2\,A}$$

The non-ideal ammeter's resistance slows down the current that it's measuring

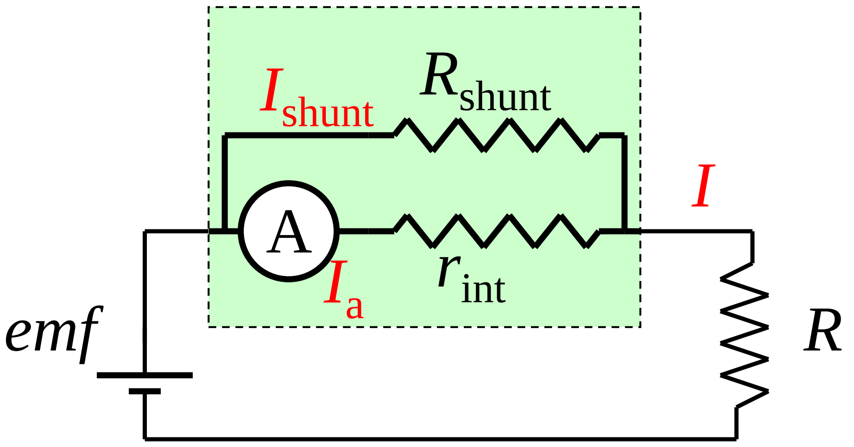
$$r_{\text{int}} I_a - R_{shunt} I_{shunt} = 0$$

$$I = I_a + I_{shunt}$$

$$r_{\text{int}} I_a - R_{shunt}(I - I_a) = 0$$

$$I_a(r_{\text{int}} + R_{shunt}) - R_{shunt} I = 0$$

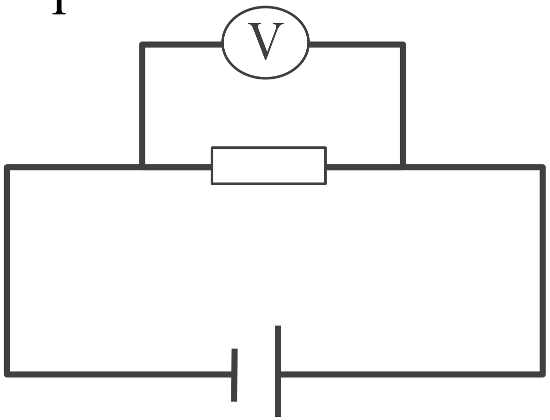
$$\boxed{I_a = \frac{R_{shunt}}{r_{\text{int}} + R_{shunt}} I}$$



Using a shunt resistor one can reduce sensitivity of an ammeter

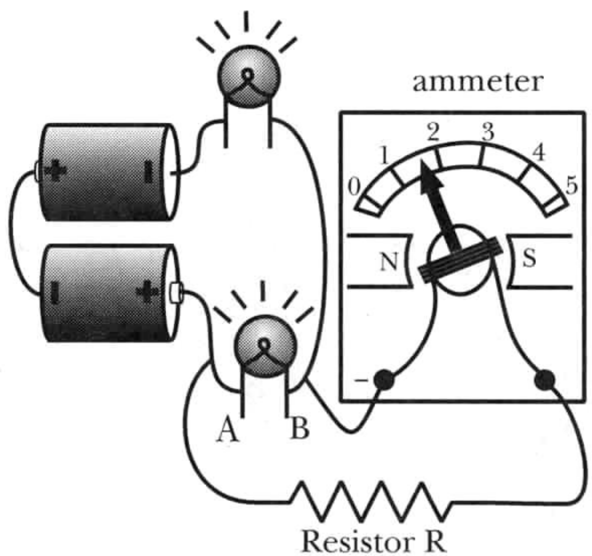
Measuring Instruments: Voltmeter

- Voltmeters are connected in parallel across the points between which potential difference is to be measured.



Connecting Voltmeter:

Higher potential must be connected to the '+' socket and lower one to the '-' socket to result in positive reading.

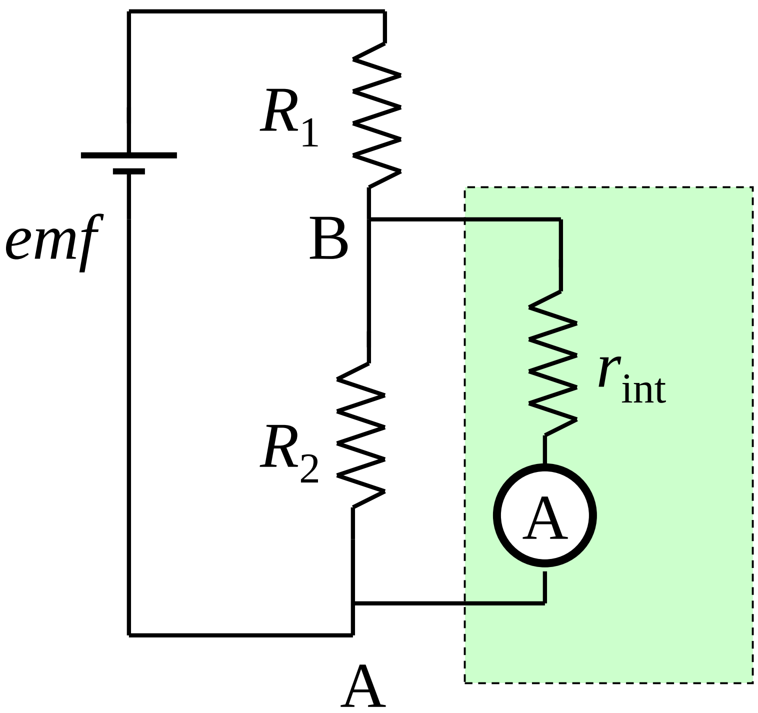


ΔV_{AB} – add a series resistor to ammeter

$$\boxed{I = \frac{\Delta V}{R}}$$

Measure I and convert to $\Delta V_{AB} = IR$

Voltmeter Internal Resistance



ΔV_{AB} in absence of a voltmeter

$$\Delta V_{AB} = \frac{R_2}{R_1 + R_2} emf$$

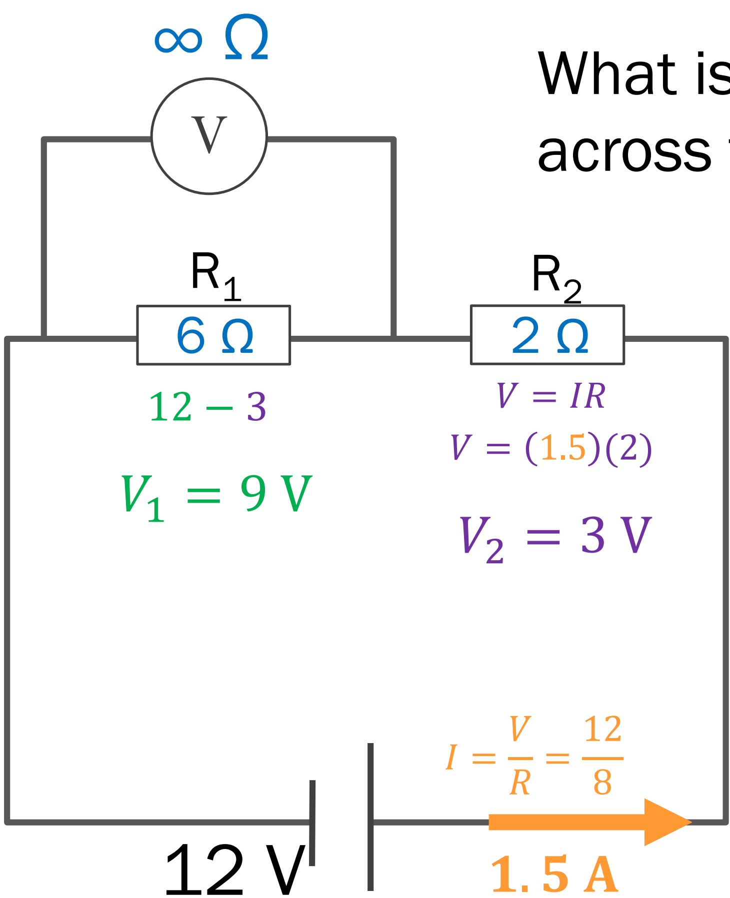
ΔV_{AB} in presence of a voltmeter

$$\Delta V_{AB} = \frac{R_{2||int}}{R_1 + R_{2||int}} emf$$

$$R_{2||int} = \frac{R_2 r_{int}}{R_2 + r_{int}}$$

Internal resistance of a voltmeter must be very large

Measuring Voltage: Ideal



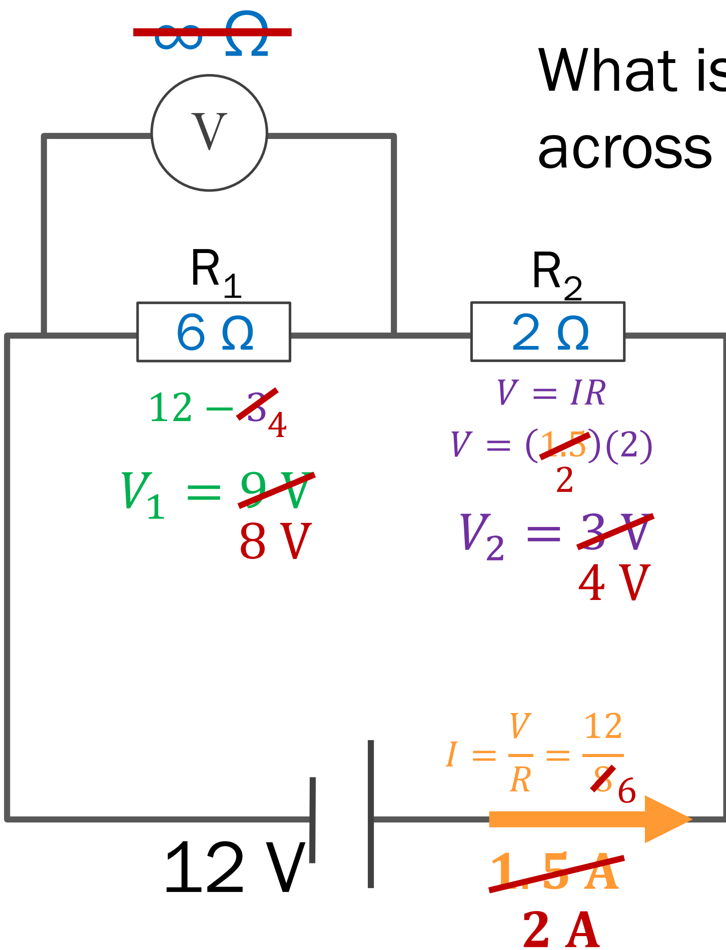
What is the reading for the ideal voltmeter across the resistor R_1?

$$R_T = \frac{1}{\frac{1}{6} + \frac{1}{\infty}} + 2$$

0

$$R_T = 6 + 2 = \mathbf{8\ \Omega}$$

Voltage: Non-ideal



What is the reading for the ~~ideal~~ 12 Ω voltmeter across the resistor R_1?

$$R_T = \frac{1}{\frac{1}{6} + \frac{1}{\underset{12}{\cancel{\infty}}}} + 2$$

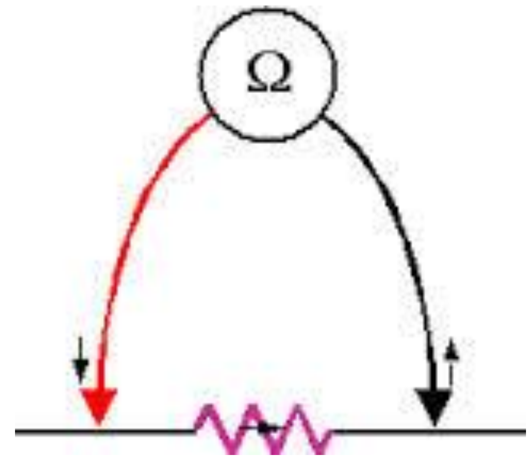
$$R_T = \underset{4}{\cancel{6}} + 2 = \underset{6\ \Omega}{\cancel{8\ \Omega}}$$

Measuring Instruments: Ohmmeter

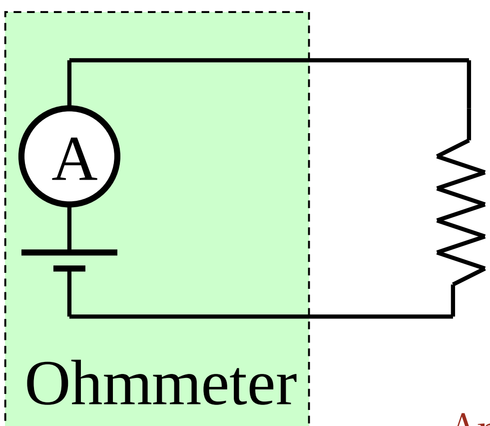
Indirect
- Measure Voltage across Resistor
- Measure Current through Resistor
- Calculate Resistance (Inaccurate)

d'Arsonval Ohmmeter
- Very Simple
- Inaccurate

Wheatstone Bridge (Most Accurate)



How would you measure R?



$$R = \frac{emf}{I}$$

$$\boxed{I = \frac{emf}{R}}$$

Ammeter with a small voltage source

Measurement Errors

- Inherent Instrument Error
- Poor Calibration
- Improper Use of Instrument
- Application of Instrument Changes What was to be Measured
  - Ideal Voltmeters have Infinite Resistance
  - Ideal Ammeters have Zero Resistance

Multimeter

- Multimeter or a multitester is a measurement instrument used in electronics, which is designed to perform tasks of several measuring instruments.
- The voltage, current, and resistance measurements can be made using different options available in a common Multimeter. Therefore, it is also called VOM (Volt Ohm meter).
- There are two types of multimeters ;analog and digital based on their measurement and display method.
- There are Analog and Digital Multimeter

Analog Multimeter

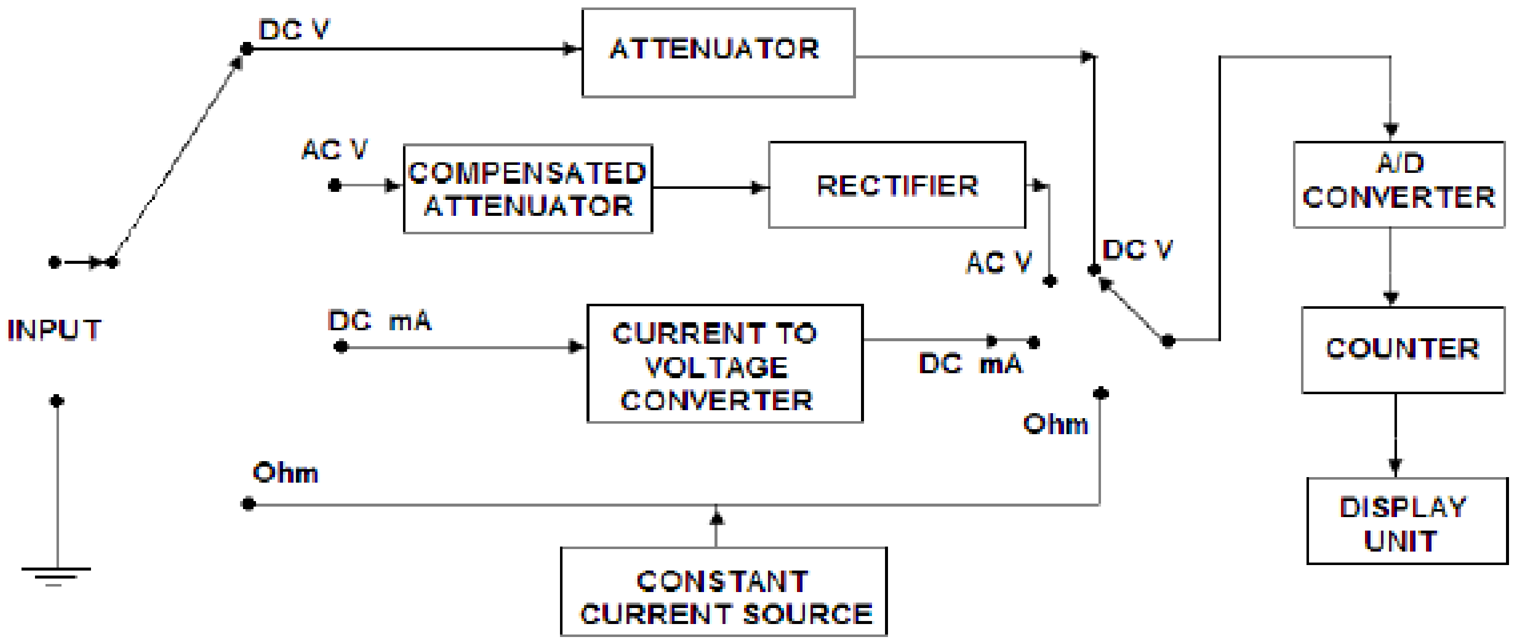
- In Analog Multimeter, continuous deflection of a pointer over a scale represents the value of quantity being measured.
- Analog meters require no power supply, they give a better visual indication of changes and suffer less from electrical noise and isolation problems.
- These meters are simple and inexpensive.

Digital Multimeter

- Digital multimeters display a numerical value as the output which has a higher accuracy than the analog multimeters.

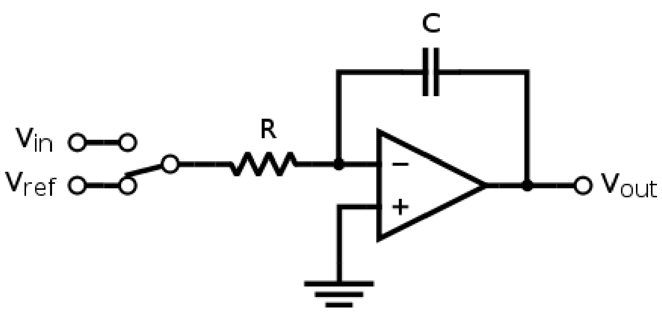
- Digital multimeter is basically a digital voltmeter and may be used for the measurement of voltage ,current (D.C or A.C) and resistance. All quantities other than D.C voltage are first converted into an equivalent D.C voltage by some device.

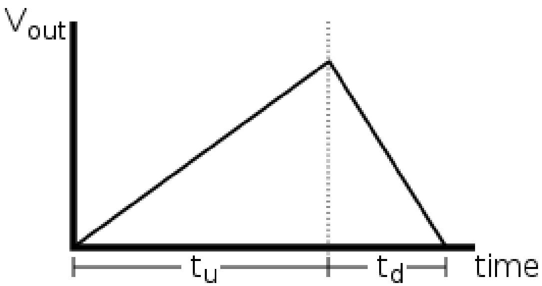
How Digital Multimeter works



- Integrating Converter
- Dependent on V_{ref}
- Dependent on Temperature
- Independent of RC

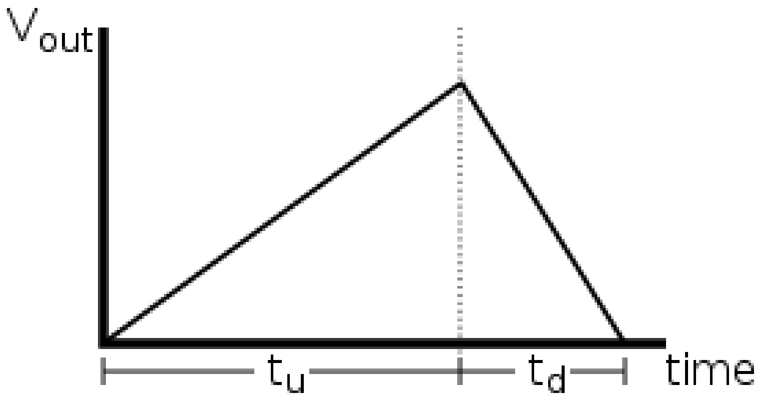
Example Voltmeter





How the DVM Works

$$V_{out-up} = -\frac{V_{in}}{RC} t_u$$



$$V_{out-down} = 0 = -\frac{V_{ref}}{RC} t_d + V_{out-up}$$

$$\frac{V_{ref}}{RC} t_d = -\frac{V_{in}}{RC} t_u$$

$$V_{in} = -V_{ref} \frac{t_d}{t_u}$$

If

$$V_{ref} = -5V \qquad R = 10k\Omega$$

$$C = 10\mu F \qquad t_u = 100ms$$

$$t_d = 50ms$$

$$V_{in} = -(-5V)\frac{50ms}{100ms} = 2.5V$$

Measuring Instruments: Multimeter

- Digital Multimeter (DMM) facilities
  - While the facilities that a digital multi-meter can offer are much greater than their analogue predecessors, the cost of DMMs is relatively low. DMMs are able to offer as standard the basic measurements that would typically include:
  - Current (DC)
  - Current (AC)
  - Voltage (DC)
  - Voltage (AC)
  - Resistance

- However, using integrated circuit technology, most DMMs are able to offer additional test capabilities. These may include some of the following:
  - Capacitance
  - Temperature
  - Frequency
  - Transistor test - hfe, etc
  - Continuity (buzzer)

Measuring Instruments: Multimeter

Analog Vs Digital Multimeters

- Analog multimeters give the output as a reading on a scale against a pointer, while digital multimeter output is in numerical form displayed on a LCD.
- Digital multimeters are more accurate than analog multimeters.
- Digital multimeters have a better range of measurements than analog multimeters.
- Digital multimeters offer additional features such as capacitance, temperature, frequency, sound level measurements and detection of semiconductor device pins (transistor / diode).
- Analog multimeters have to be calibrated manually, while most digital multimeters are calibrated automatically before every measurement.
- Analog multimeters are less costly while digital multimeters are expensive.

DMM

Used to measure Voltage, Current, and Resistance

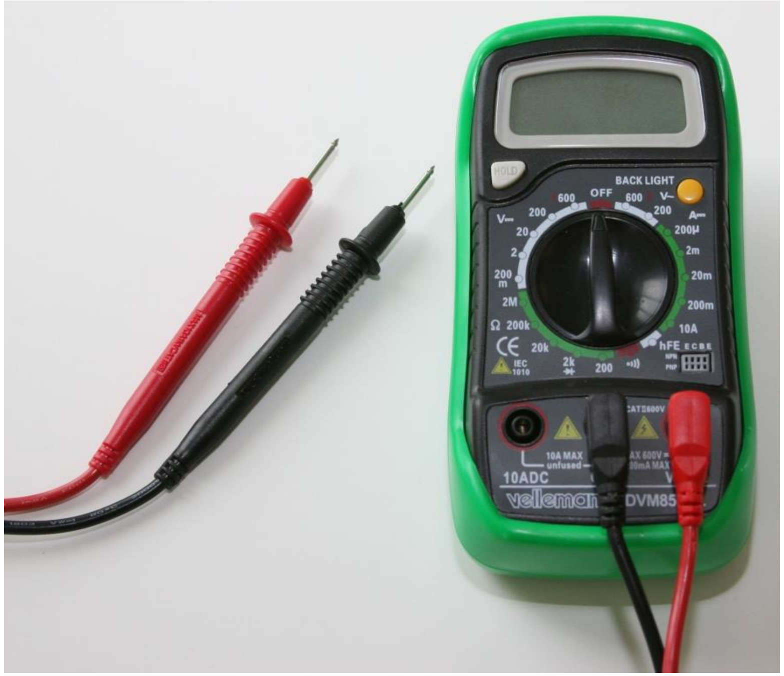
Symbol

(V ---) Voltage Direct Current

(V ~) Voltage Alternating Current

(A ---) Current

(Ω) Resistance



Traditional Digital Multimeter (DMM)

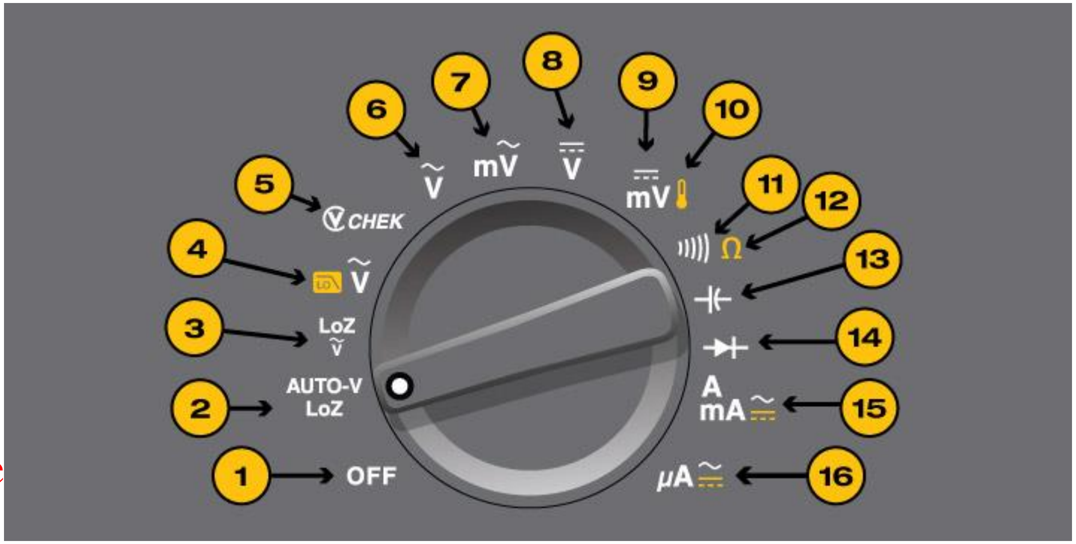
In this activity you will learn how to measure voltage.

DMM Display

- Multimeter consists of:
- Display
  - (1) Digits
  - (6) Negative indicator
  - (15) Measurement units
  - (3) Continuity beeper
- Selection Knob
- Ports

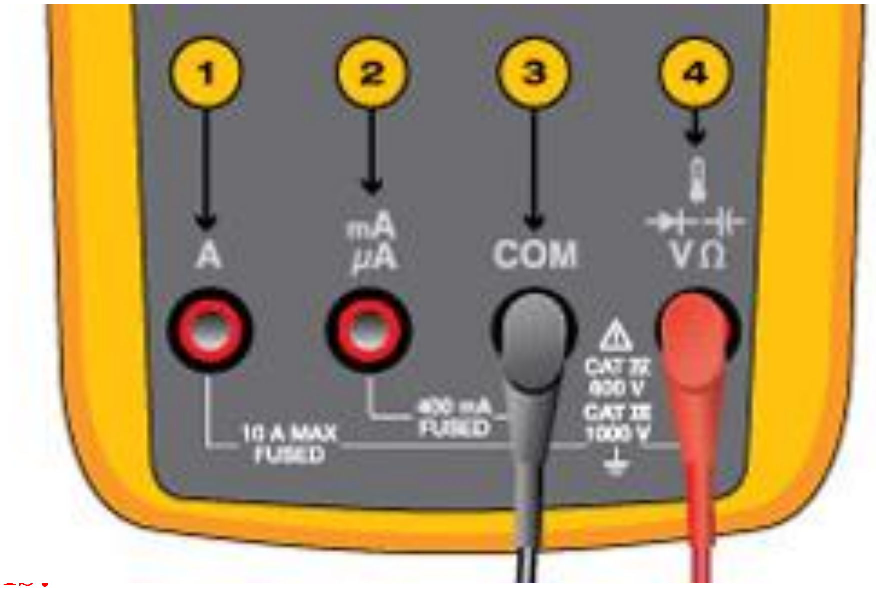
DMM Selection Dial

- Multimeter consists of:
- Display
- Selection Knob
  - (1) ON/OFF
  - (6, 7) AC voltages
  - (8, 9) DC voltages
  - (12) Resistance
  - (14) Diode
  - (15, 16) Current (move le
- Ports



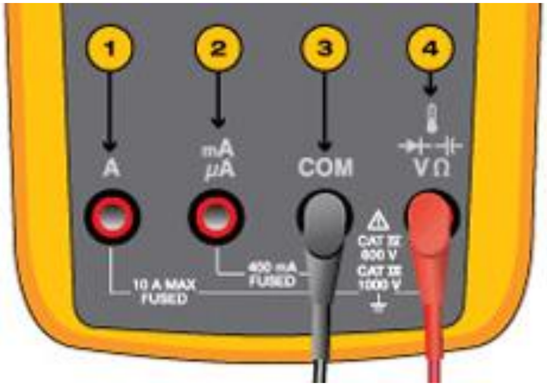
DMM Ports

- Multimeter consists of:
- Display
- Selection Knob
- Ports
  - Common
  - Voltage
  - Current (A , mA/**µ**A)
  - Read carefully! Meters ha different port configurati



DMM Measurements: Continuity

- **<u>Measure Continuity:</u>**
- Test fuses
- Open or completed electrical connections
- *Ring out* a wire to identify
- Connect to *Com* and *V* ports, and set selector switch to:
-

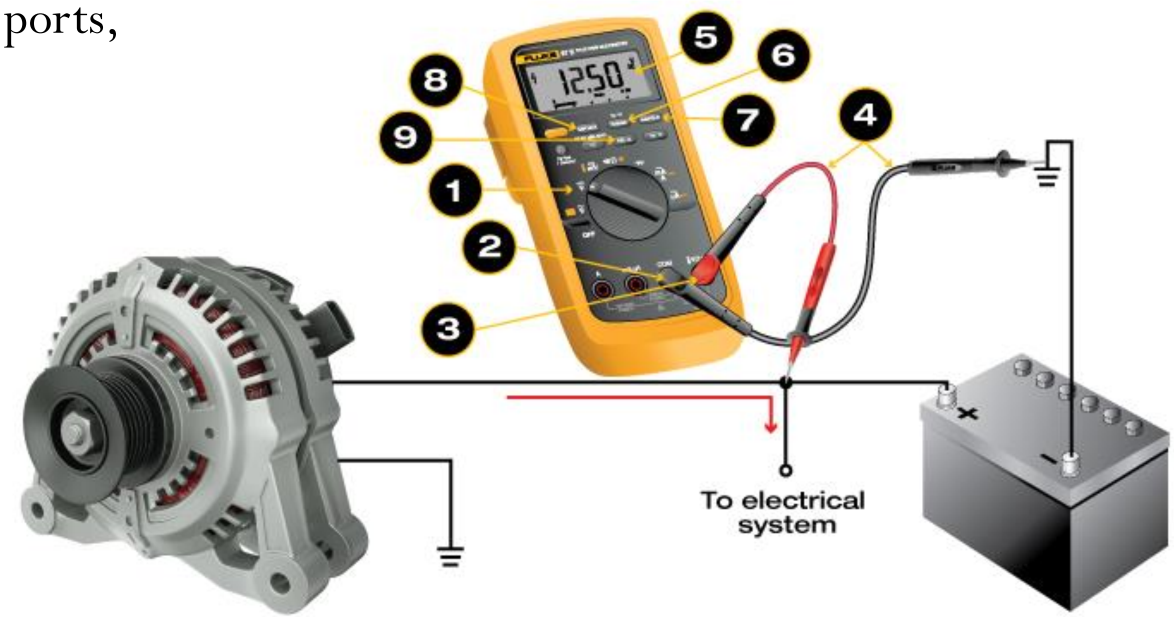


DMM Measurements: Resistance (Ω)

- Deenergized circuits only!
- Check resistor values
- Check for open circuits
- Check for adequate ground connection

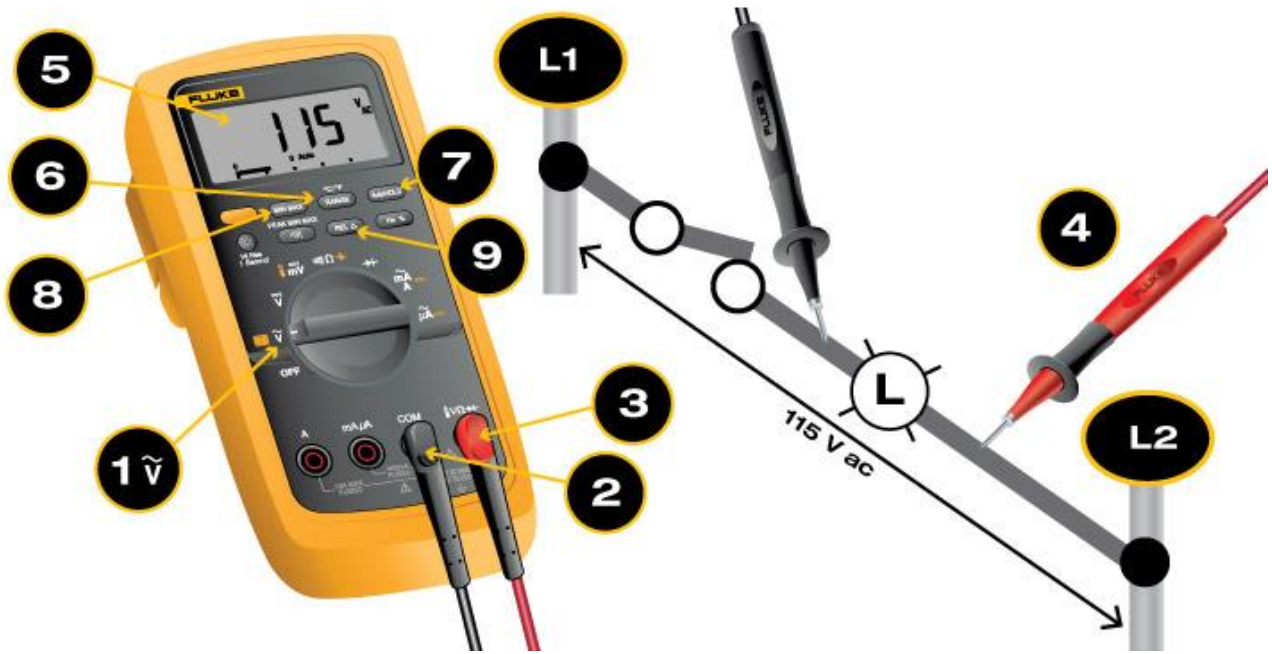
DMM Measurements: DC Voltage

- Check for Voltage within a circuit
- Leads are in parallel with circuit
- Connect to "*Com*" and "*V*" ports, and set selector switch to: or mV
-



DMM Measurements: AC Voltage

- Leads are in parallel with circuit
- Connect to *Com* and *V* ports, and set selector switch to :   or mV
-



DMM Measurements: Current

- Check for Current within a circuit or branch
- Leads are in series with circuit
- Current flows through the meter!

Connect to *Com* and (10A/A*)* ports. Set selector switch to mÃ/Ã for AC amps; or mADC for DC amps.

Note: If a meter includes fused current terminals, verify that its fuses are good.