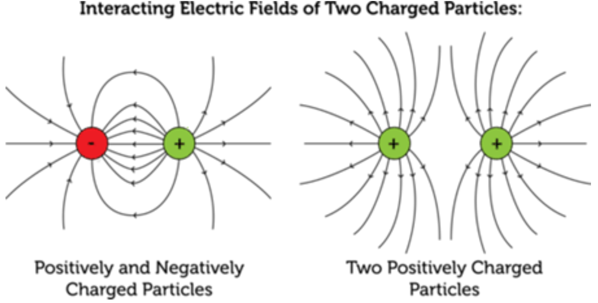
Design of Data Acquisition Systems Electronics

Theory

What will be covered

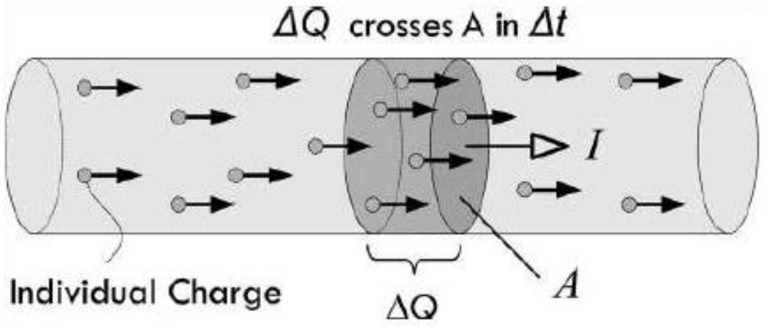
- Basic electrical concepts: current, voltage, resistance
- Resistance, capacitance, inductance and power
- Circuit analysis methods (Ohm’s, Kirchhoff’s, Thevenin’s Laws)
- Real-world effects like heat, grounding, and wire resistance

Electric current



- Electric current means **how much electric charge flows past a point (or through an area) every second**.
- Imagine water flowing in a pipe: instead of liters of water per second, we measure **coulombs of charge per second**.

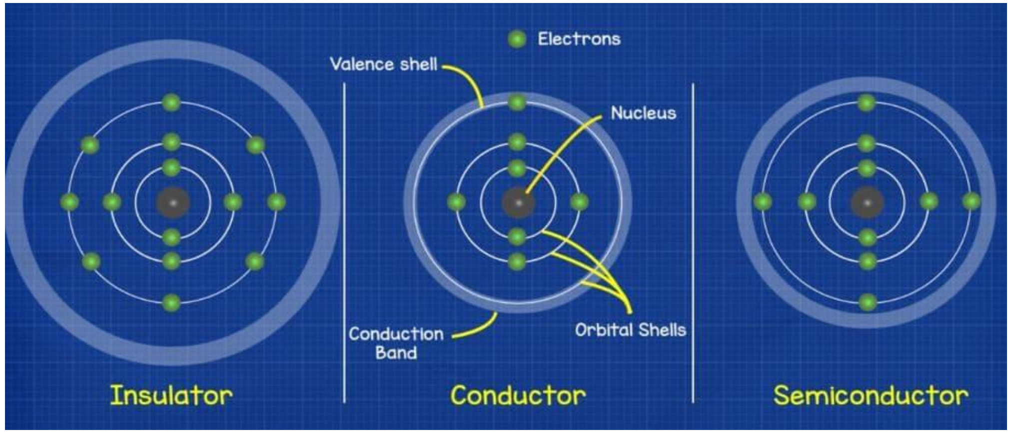
$$I_{\text{ave}} = \frac{\Delta Q}{\Delta t}$$

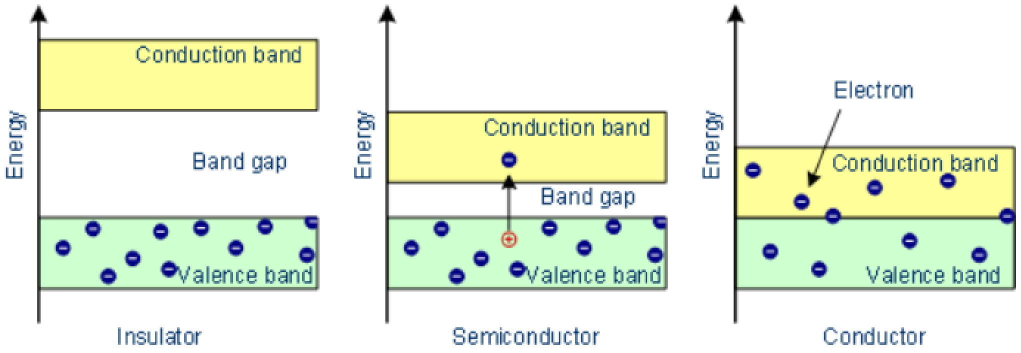


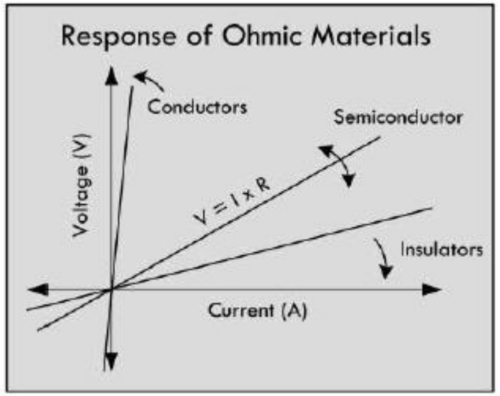
$$1\,\text{A} = 1\,\text{C/s}$$

- The unit of current is coulombs per second, but this unit is also called the ampere (A), named after Andre-Marie Ampere.
- Within conductors such as copper, electrical current is made up of free electrons moving through a lattice of copper ions.
- The charge on a single electron is given by: $Q_{\text{electron}} = (-e) = -1.602 \times 10^{-19}\ \text{C}$
- If a current of 1 A flows through a copper wire, the number of electrons flowing by a cross section of the wire in 1 s is equal to:

$$1\ \text{A} = \left(\frac{1\ \text{C}}{1\ \text{s}}\right)\left(\frac{\text{electron}}{-1.602 \times 10^{-19}\ \text{C}}\right) = -6.24 \times 10^{18}\ \text{electrons/s}$$







Materials

Conductors

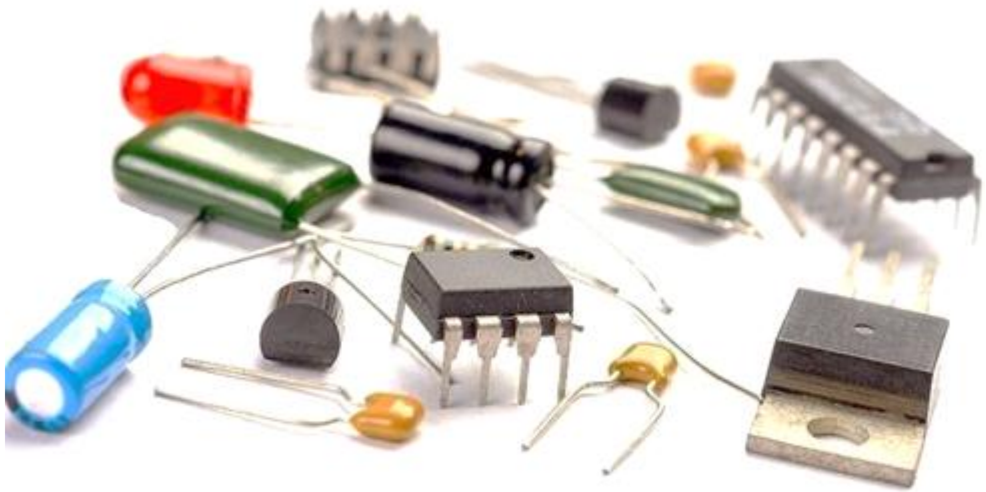
- Materials that allow electric current to flow easily.
- They have **lots of free electrons** (valence electrons loosely bound).
- Copper, aluminum, gold, silver.
- Very **low resistance** → used in wires, cables, and circuits.

Insulators

- Materials that **do not allow current** to flow easily.
- Their electrons are **tightly bound** to atoms (no free charge carriers).
- Rubber, glass, plastic, wood, ceramics.
- Very **high resistance** → used to protect us from electric shock.

Semiconductors

- Materials with electrical properties **between conductors and insulators**.
- At low energy (room temperature) they act like insulators, but if given energy (heat, light, voltage, or doping with impurities), they can conduct.
- Silicon (Si), Germanium (Ge), Gallium arsenide (GaAs).
- Basis of **modern electronics** (diodes, transistors, integrated circuits).



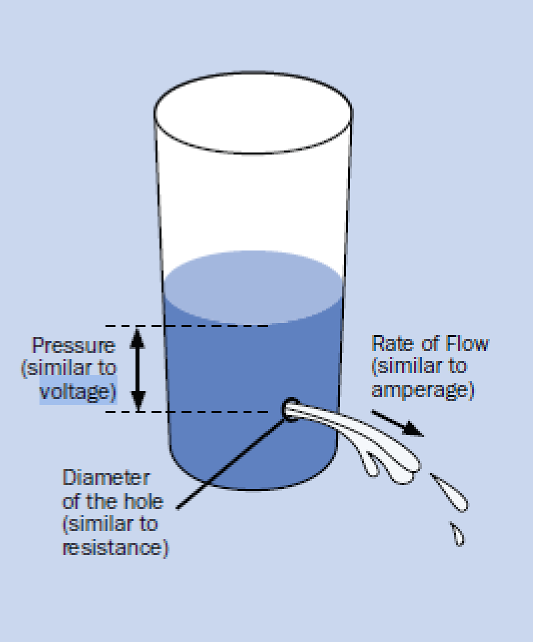
Design of Data Acquisition Systems Electronics

Components

Analogy: voltage and current

EL	Hydraulic
Voltage	Pressure
Current (charge/second)	Current (water/second)

Voltage

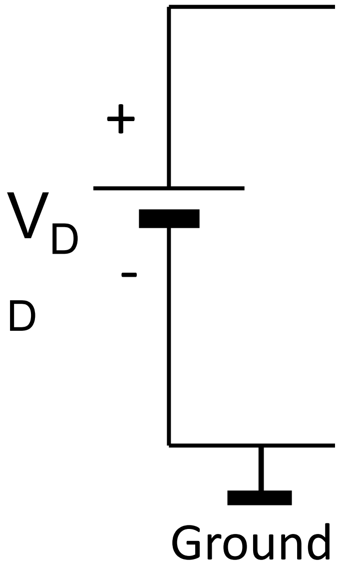


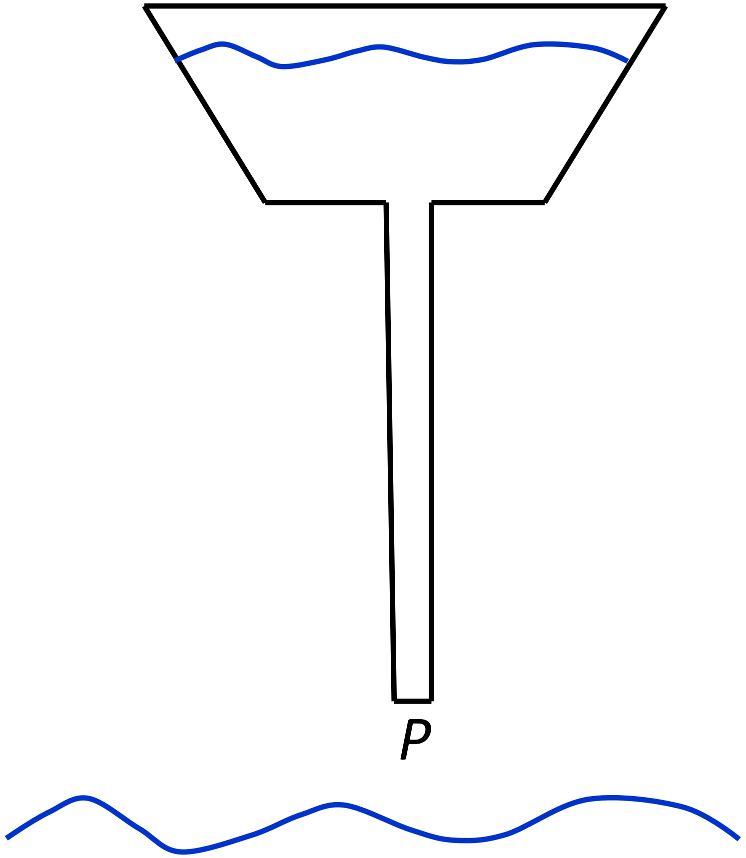
- Voltage is trying to push current.
- Like (water) pressure is trying to push (water) current.

- There are only voltage <u>differences</u>
- When reference point not mentioned: ground.

Voltage

A **voltage source** is an element in an electrical circuit that provides a specified **potential difference (voltage)** between its terminals, independent of the current flowing through it.





Definition of Volt and Generalized Power Law

Volt (V)—the unit of measure of voltage

$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}, \; 1 \text{ V} \frac{1 \text{ J}}{1 \text{ C}} = \text{J/C (Energy definition)}$$

Two points with a voltage of 1 V between them have enough “pressure” to perform 1 J worth of work while moving 1 C worth of charge between the points. For example, an ideal 1.5- V battery is capable of moving 1 C of charge through a circuit while performing 1.5 J worth of work.

Another way to define a volt is in terms of **power**, which happens to be more useful in electronics. Power represents how much energy per second goes into powering a circuit.

P=VI, and V=P/I

In terms of power, then, the volt is defined as:

$$1 \text{ volt} = \frac{1 \text{ watt}}{1 \text{ amp}}, \; 1 \text{ V} = \frac{1 \text{ W}}{1 \text{ A}} = \text{W/A}$$

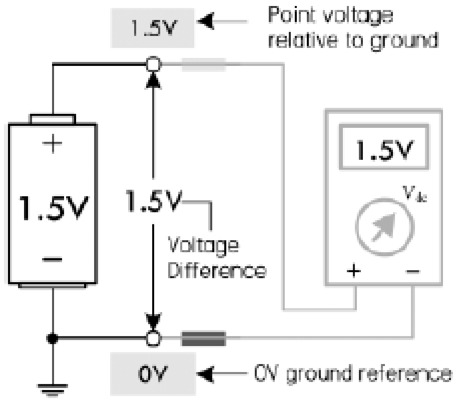
Example: Our 1.5- V flashlight circuit draws 0.1 A. How much power does the circuit consume?

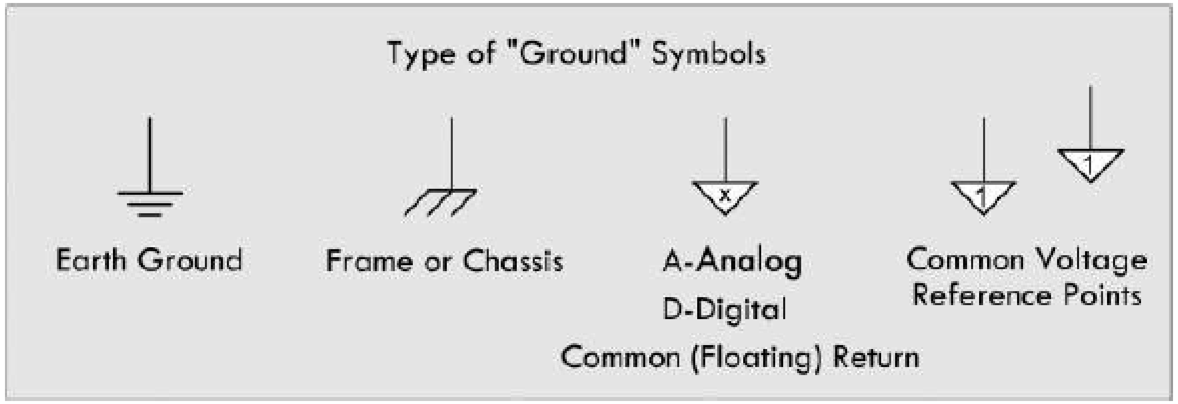
P = VI = (1.5 V)(0.1 A) = 0.15 W

Book: PRACTICAL ELECTRONICS FOR INVENTORS – CH2 – 2.3.2

Grounding

- It is common practice to connect one or more nodes in a circuit to “ground”. All voltages are then expressed w.r.t. this ground.
- The first reason to use grouding is the ease of using ground as a reference for all other points in the circuit, as we discussed above.
- The second reason is for safety; the outside of a piece of equipment is often connected to ground so that in case of accidental voltages on the casing the fuse in your house will blow instead of electrocuting the person touching it.





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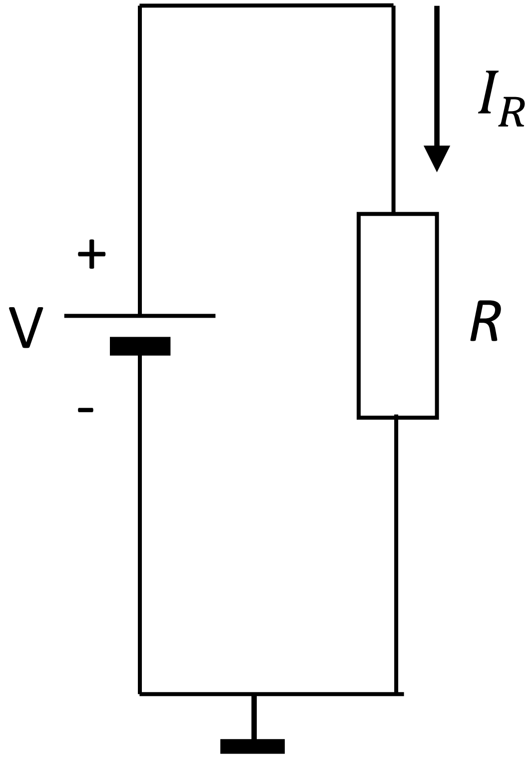
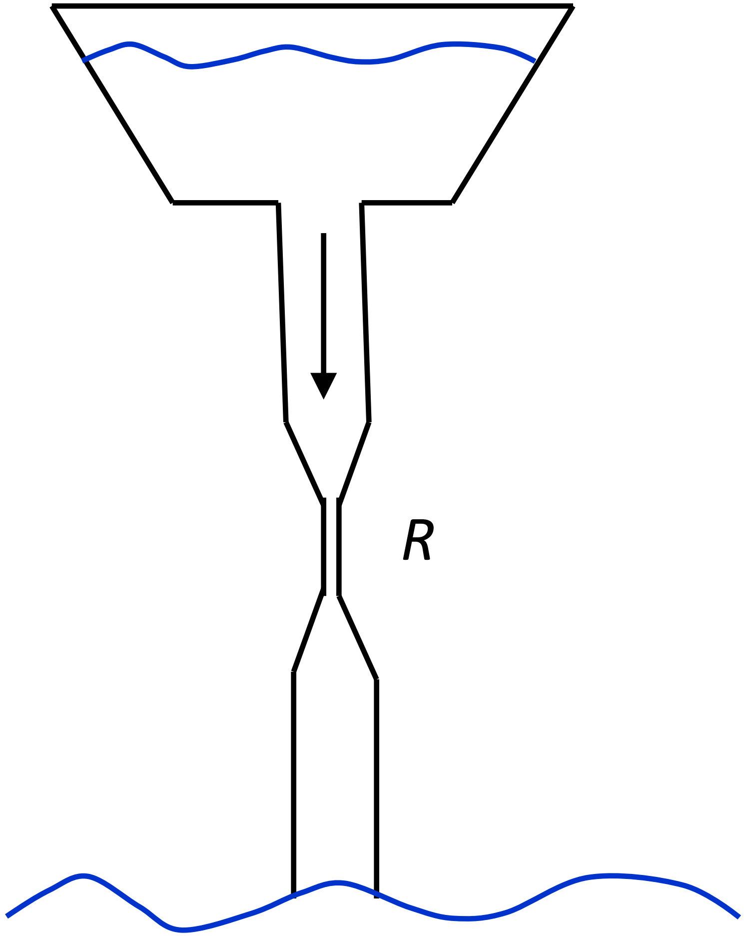
Resistance

Resistance is the property of a material or component that **opposes the flow of electric current**.



$$I_R = \frac{V}{R}$$



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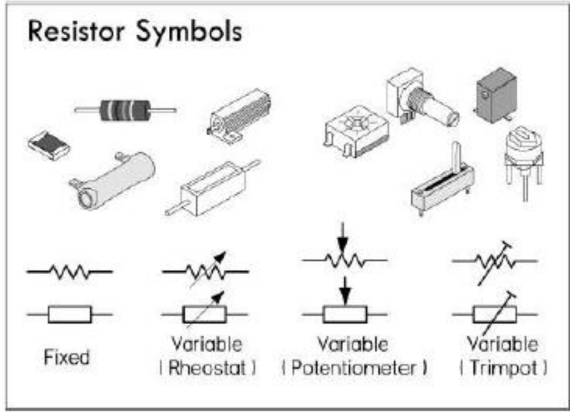
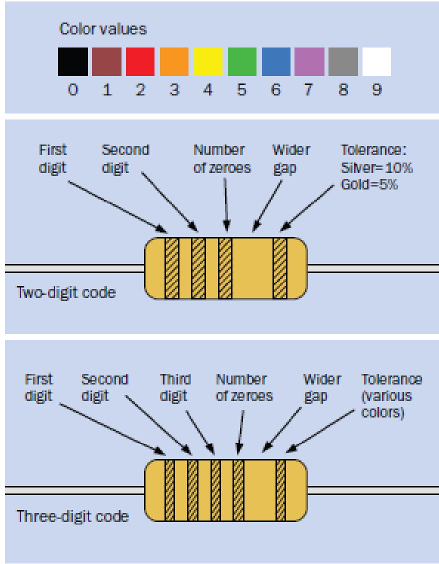
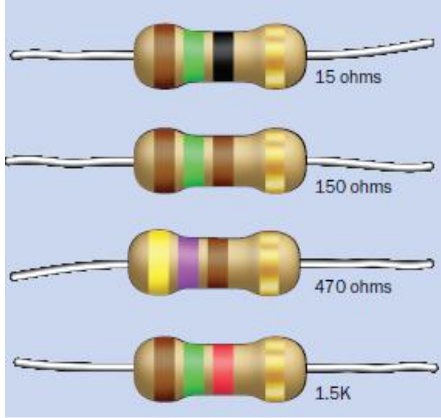
Book: Make:Electronics – Experimetn 3

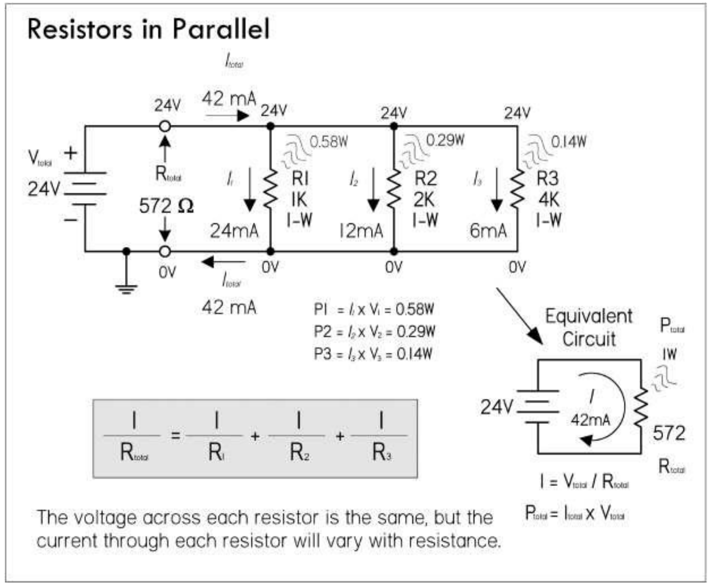
Resistor

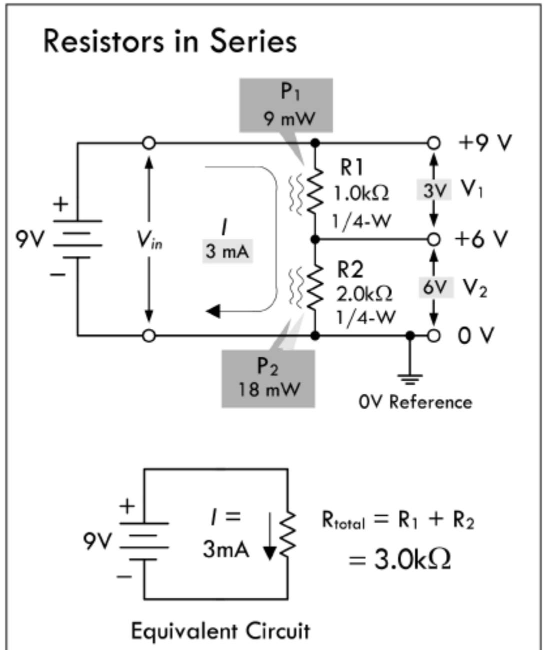


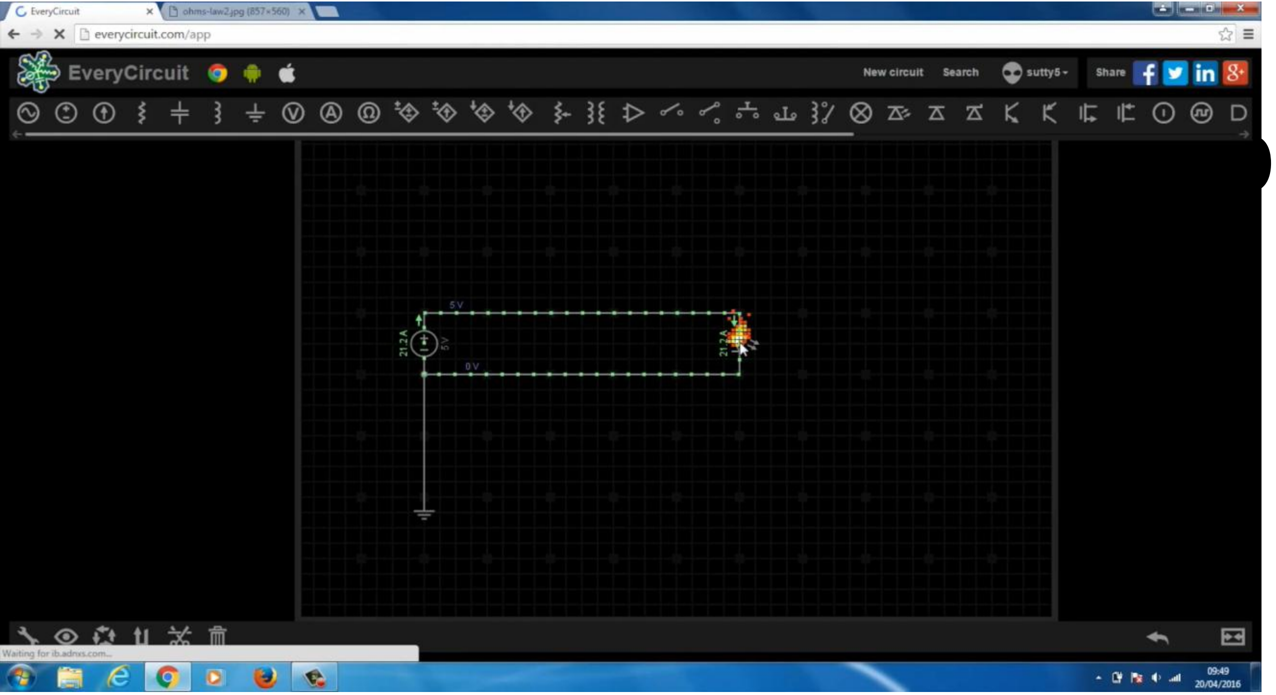


- **Resistors** are devices used in circuits to **limit current flow** or to **set voltage levels** within circuits.
- When two or more resistors are placed in **parallel**, the voltage across each resistor is the same, but the current through each resistor will vary with resistance.
- Total resistance of the combination will be lower than that of the lowest resistance value present.
- When a circuit has a number of resistors connected in **series**, the total resistance of the circuit **is the sum of the individual resistances**.

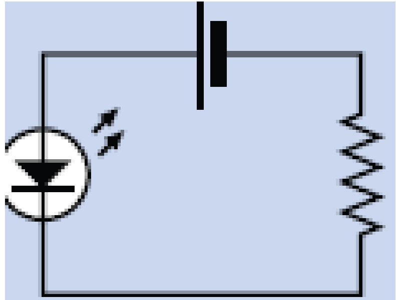


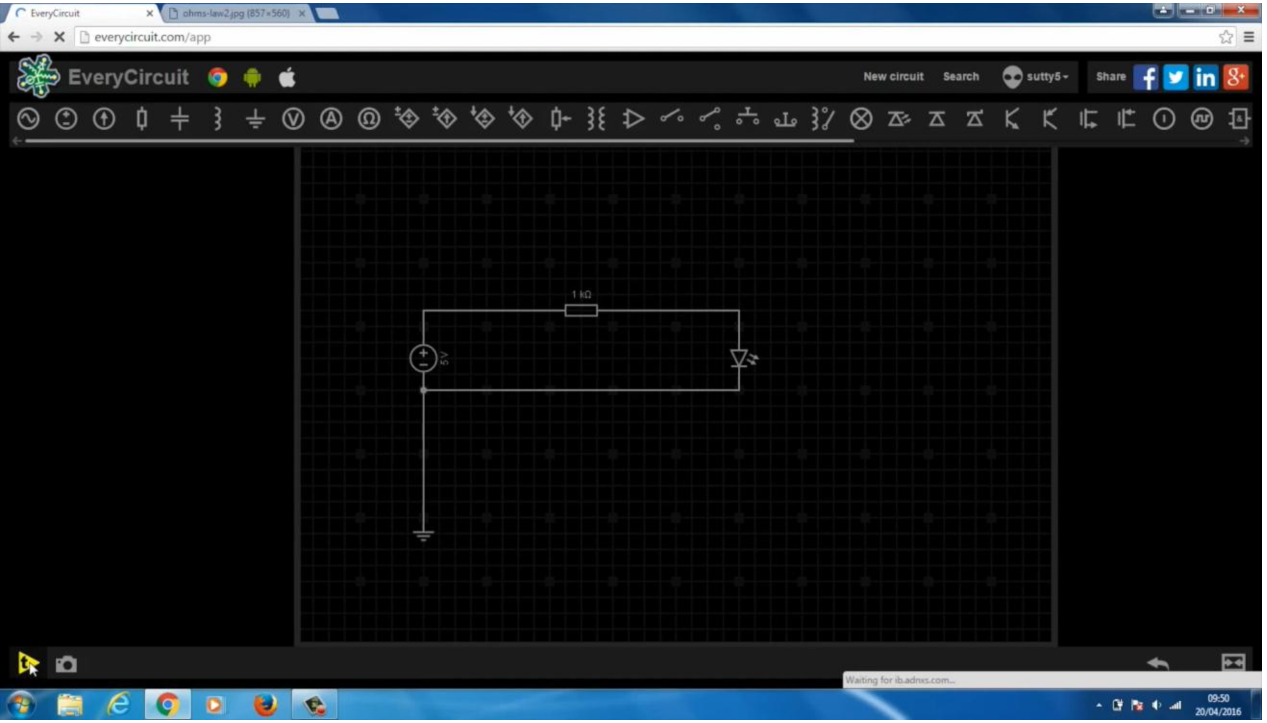


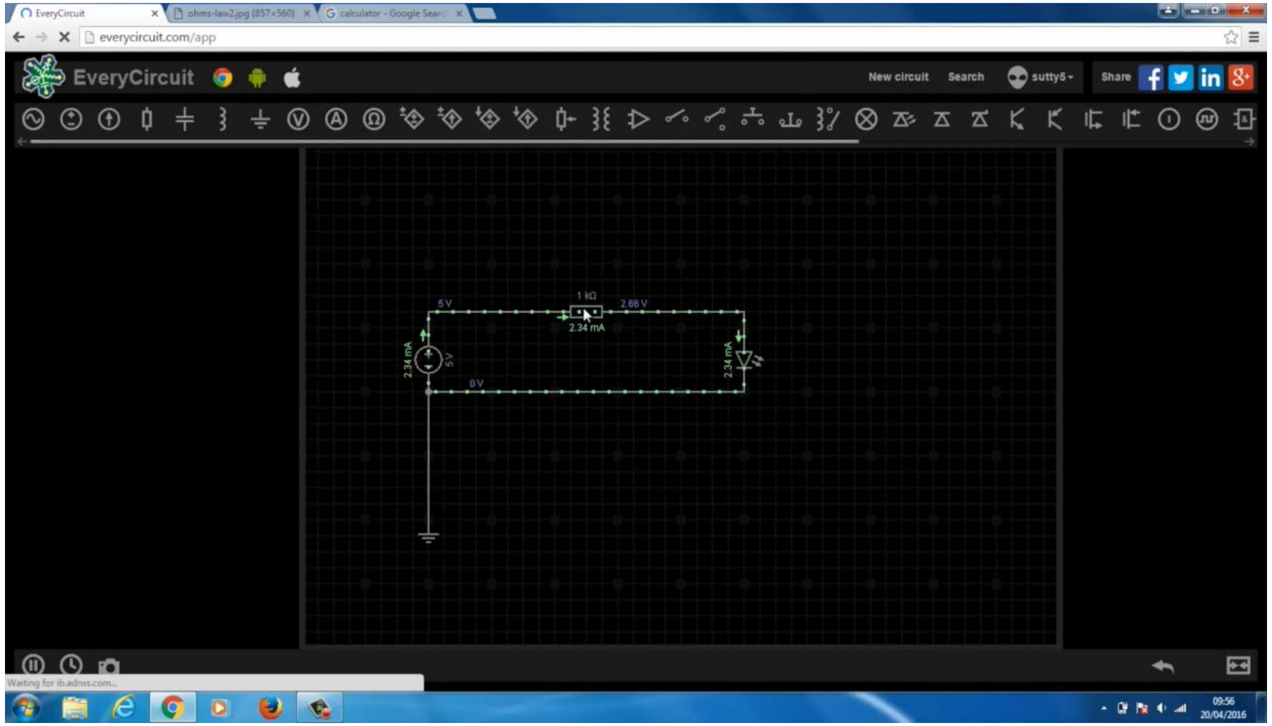




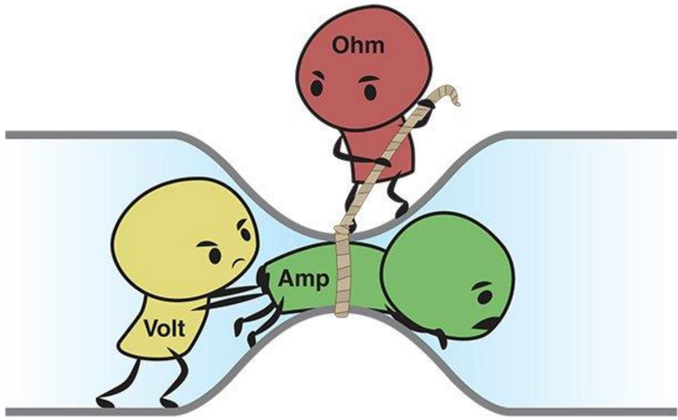
le in the circuit



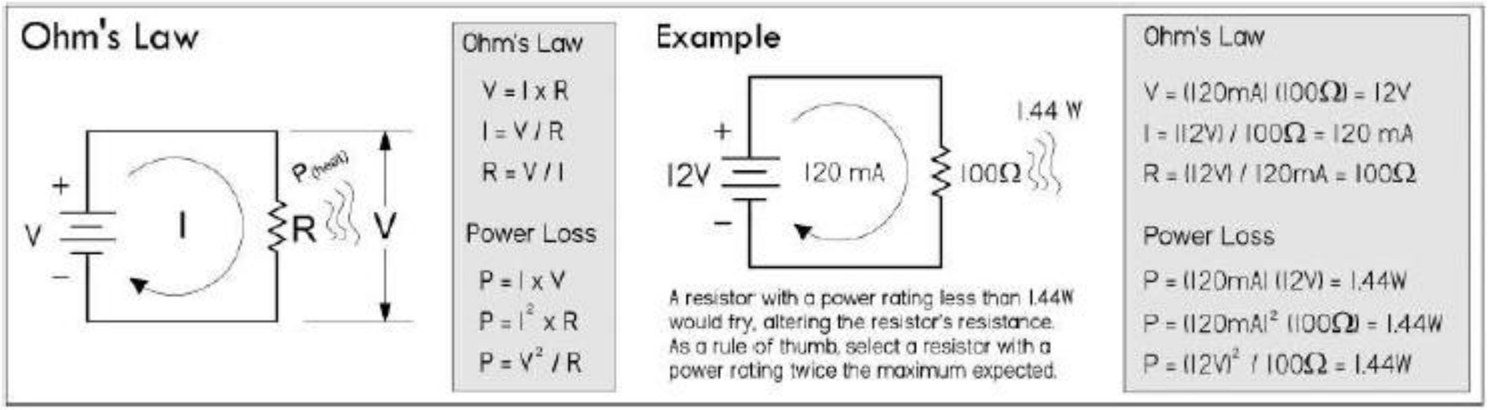




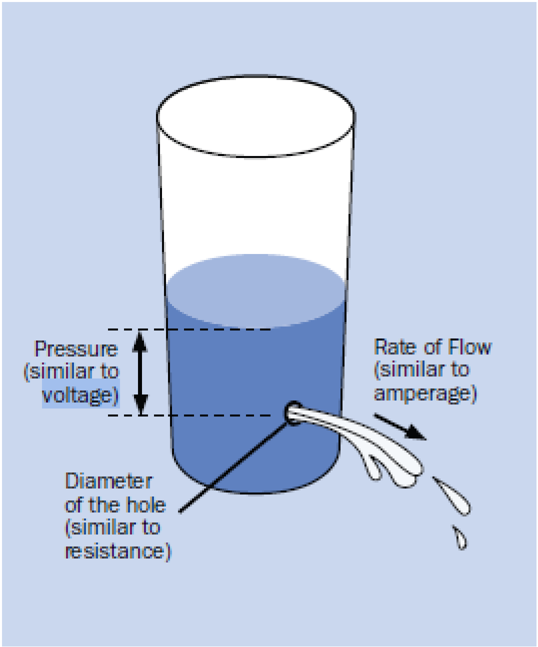
Ohm's Law



Ohm
Amp
Volt



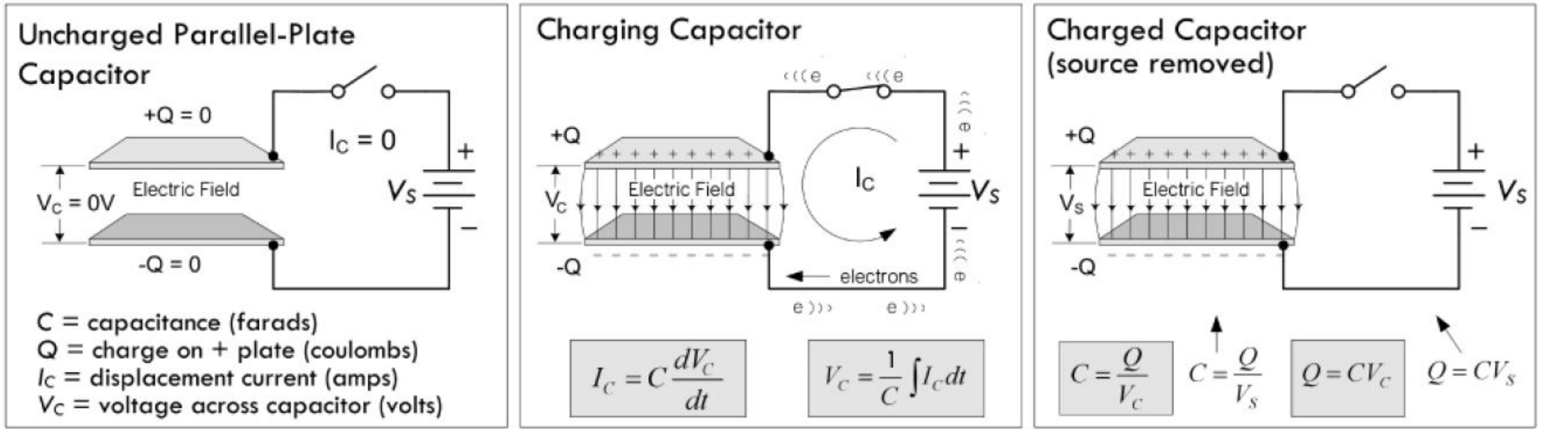
Ohm's Law
V
I
R
V
P (heat)
Ohm's Law
V = I x R
I = V / R
R = V / I
Power Loss
P = I x V
P = I² x R
P = V² / R
Example
12V
120 mA
100Ω
1.44 W
A resistor with a power rating less than 1.44W would fry, altering the resistor's resistance. As a rule of thumb, select a resistor with a power rating twice the maximum expected.
Ohm's Law
V = (120mA) (100Ω) = 12V
I = (12V) / 100Ω = 120 mA
R = (12V) / 120mA = 100Ω
Power Loss
P = (120mA) (12V) = 1.44W
P = (120mA)² (100Ω) = 1.44W
P = (12V)² / 100Ω = 1.44W



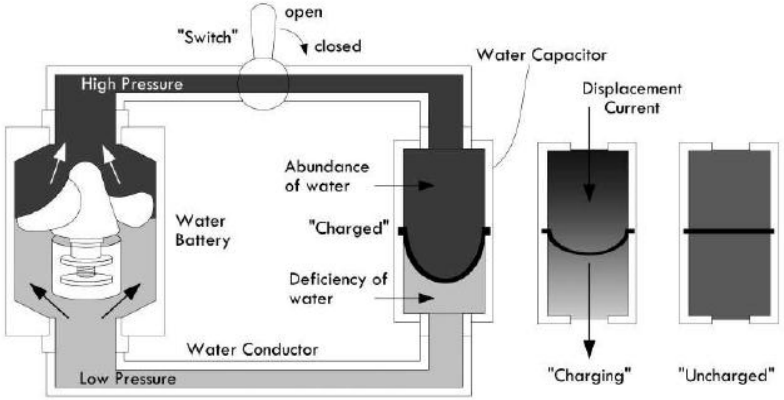
Pressure (similar to voltage)
Rate of Flow (similar to amperage)
Diameter of the hole (similar to resistance)

Capacitance

- If you take two oppositely charged parallel conducting plates separated a small distance apart by an insulator—such as air or a dielectric such as ceramic—you have created what's called a capacitor.

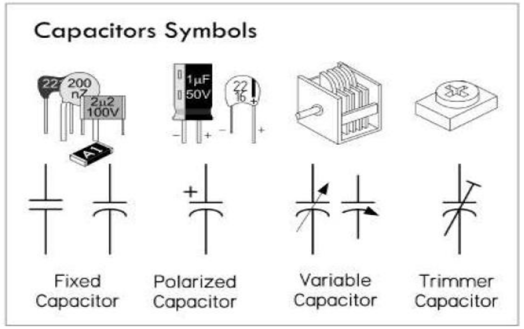


Capacitor Water Analogy

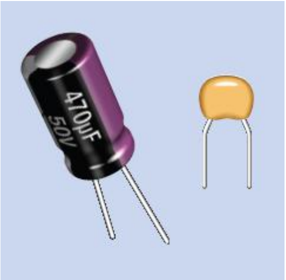


- The ratio of charge on one of the plates of a capacitor to the voltage that exists between the plates is called capacitance (symbolized C): **C= Q /V** **Capacitance** has **units of farads** (abbreviated F). (After Micheal Faraday)
- One farad is equal to one coulomb per volt: 1 F = 1 C/1 V

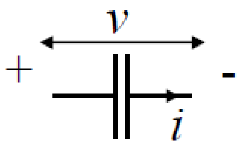
Book: PRACTICAL ELECTRONICS FOR INVENTORS – CH2 – 2.23, 2.23.6, 2.23.10, 2.23.11
Book: Make:Electronics – Experimetn 9



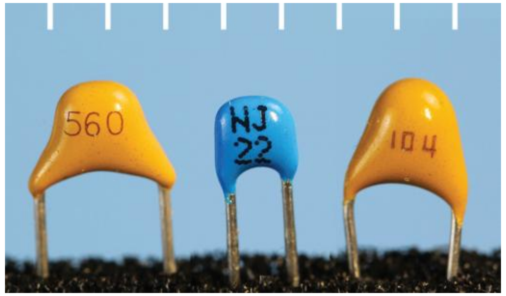
Capacitor



- Devices that are specifically designed to hold charge (electrical energy in the form of an electric field) are called **capacitors**. (In fact, a capacitor will also block DC current—generally speaking—because the plates inside it don't touch each other.)

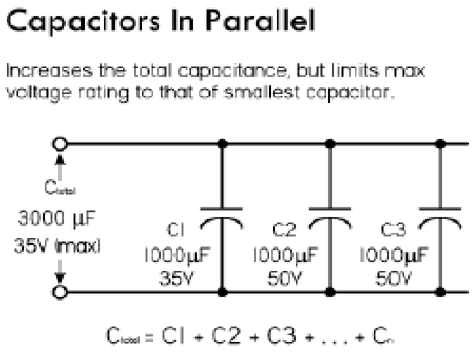


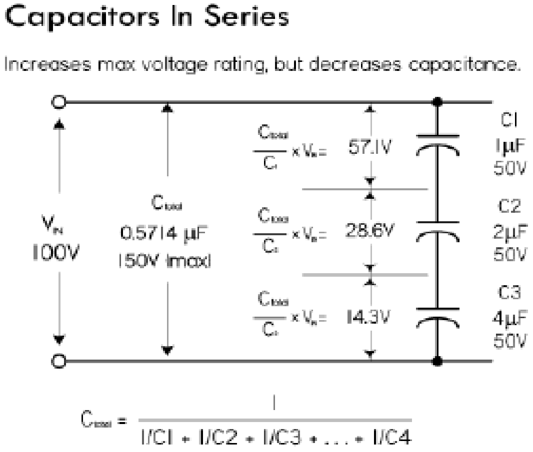
$$v = \frac{1}{C}\int i\,dt \qquad i = C\frac{dv}{dt}$$



- **Ceramic capacitors** usually look like little discs or blobs, like the one on the right.
- **Electrolytic capacitors** are shaped like miniature tin cans, wrapped in thin plastic filmcolor

- Most commercial capacitors are limited to a range from 1 pF to 4700 µF





As you can see, a ceramic capacitor usually has a code printed on it. Here's how to read it:
First two numerals: The beginning of the value of the capacitor.
Third numeral: The number of subsequent zeroes.

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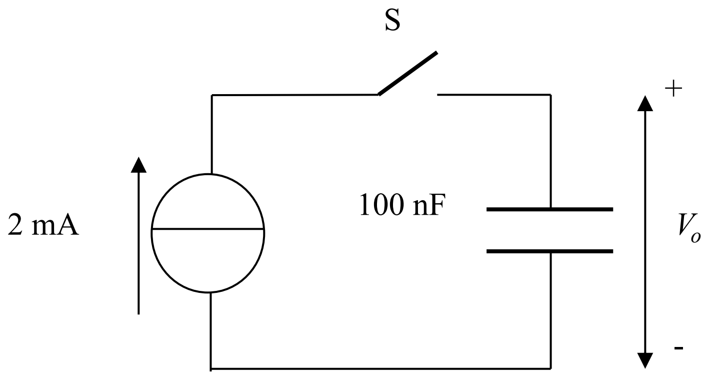
Book: Make:Electronics – Experimetn 9

Simple question

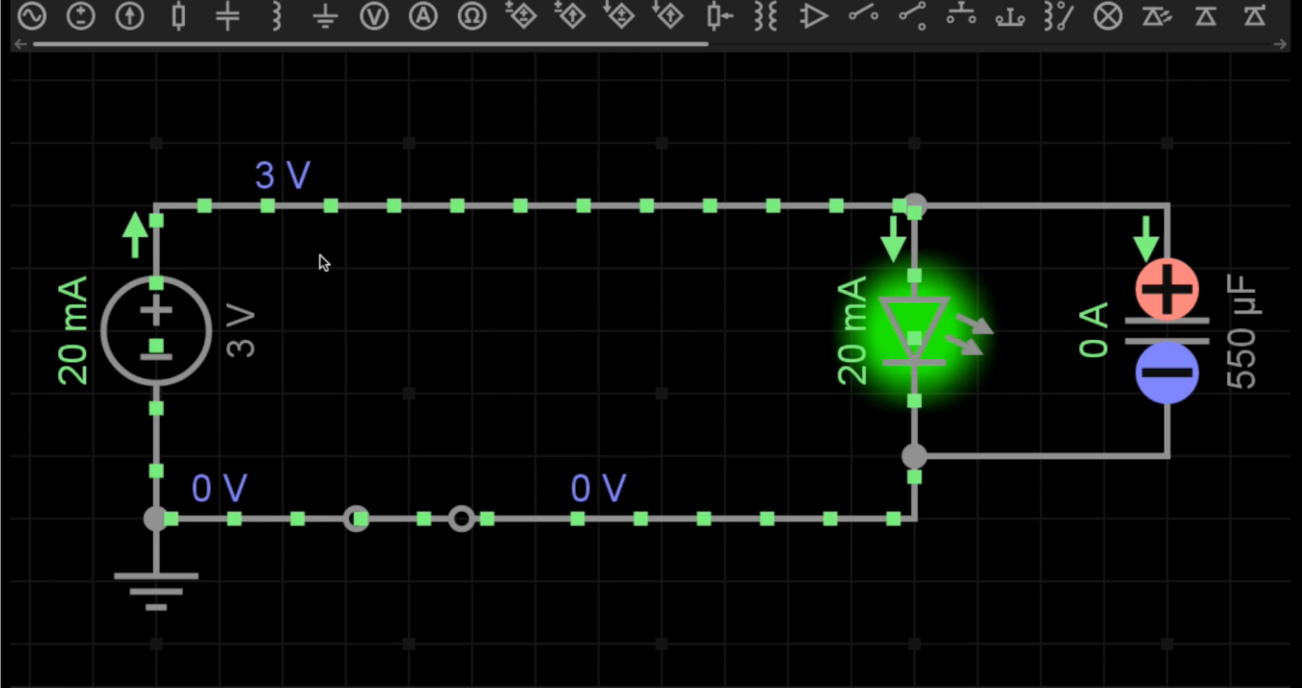
- What is the voltage V_0 at t = 0.5ms? At t = 0 the capacitor is not charged (V_0 = 0V)

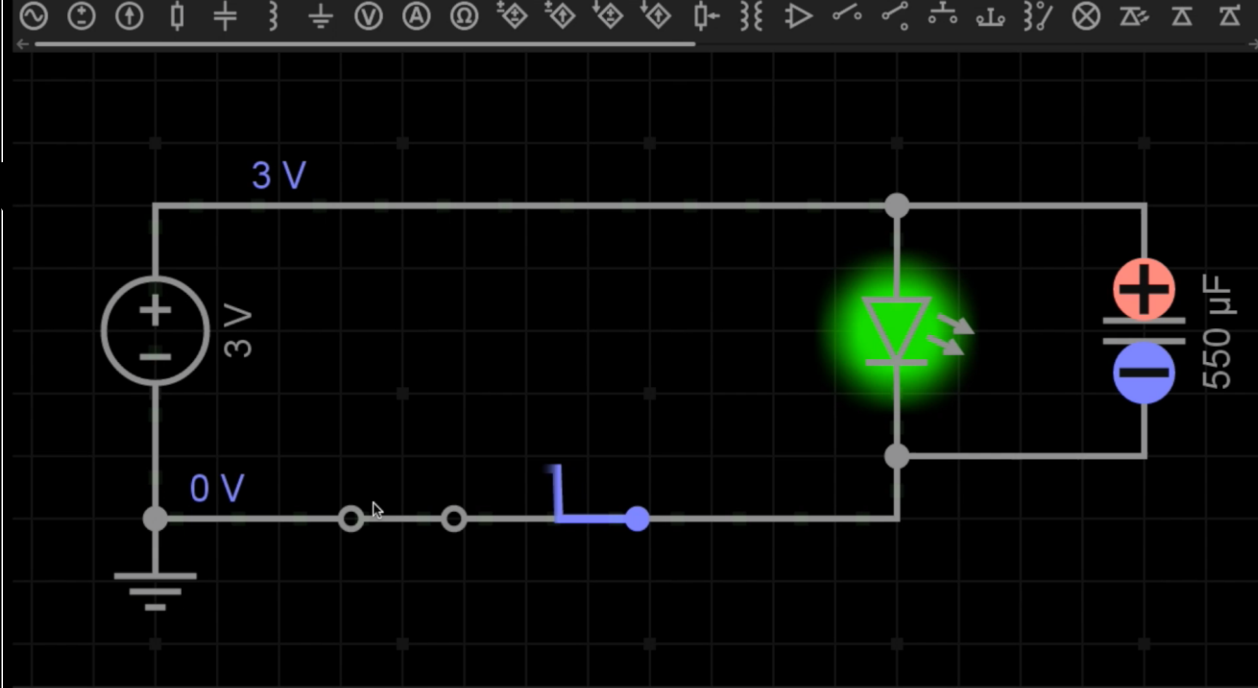


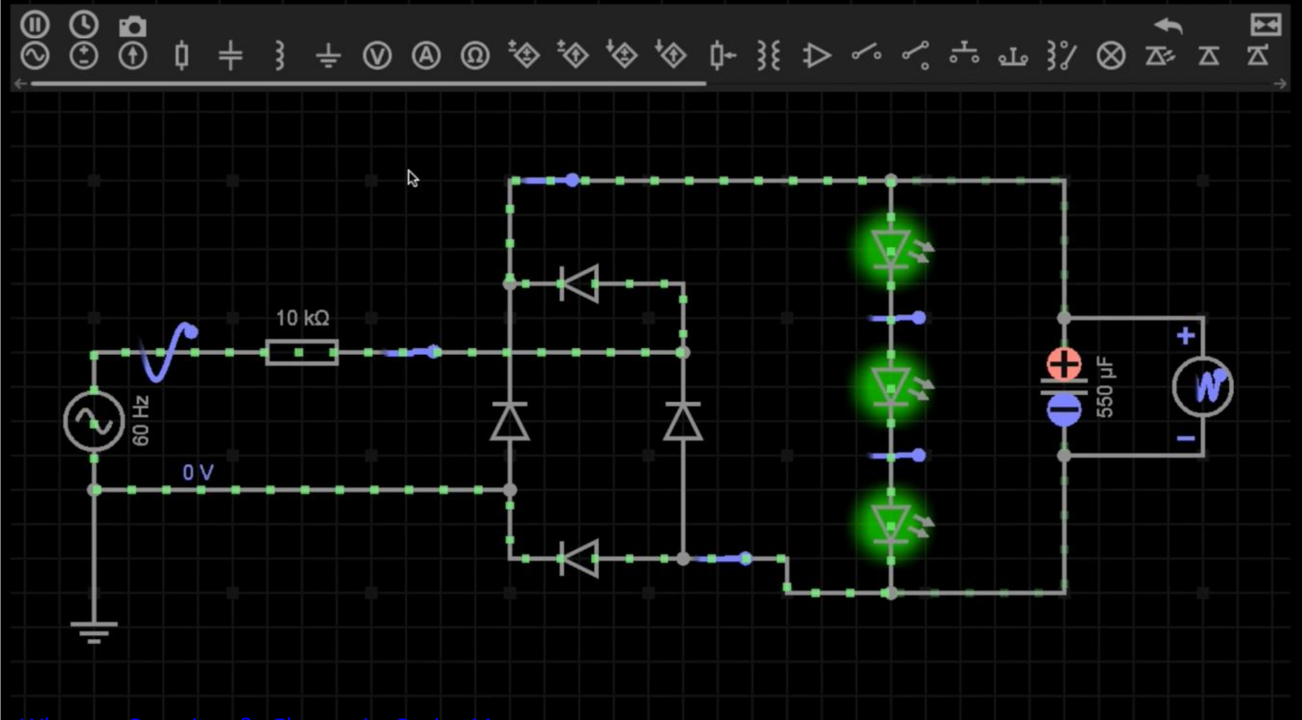
C = 100·10^{-9} F,
i = 2·10^{-3} A,
dt = 0.5·10^{-3}s

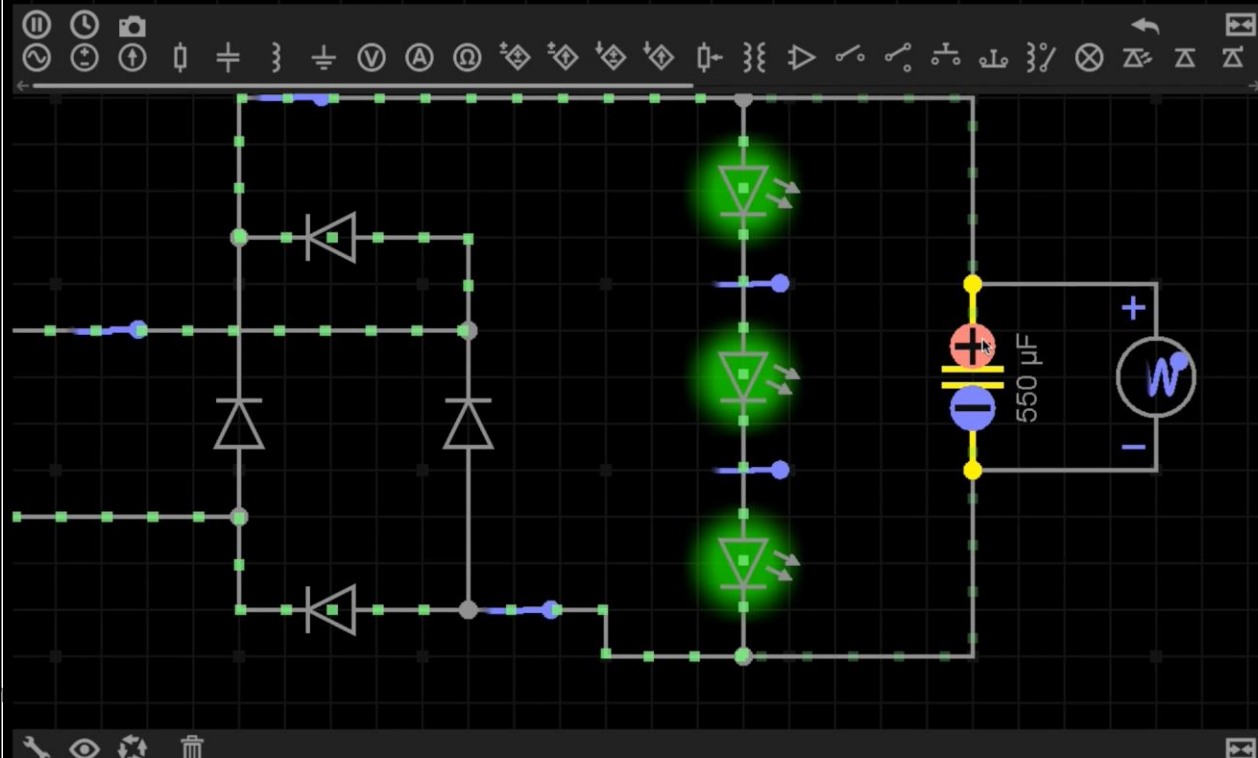
$$v_C = \frac{1}{C}\int i\,dt = 10^7 \int_0^{5\cdot 10^{-4}} 2\cdot 10^{-3} dt$$

$$= 10^7 \cdot 2 \cdot 10^{-3} \cdot 5 \cdot 10^{-4} = 10\ [\mathrm{V}]$$



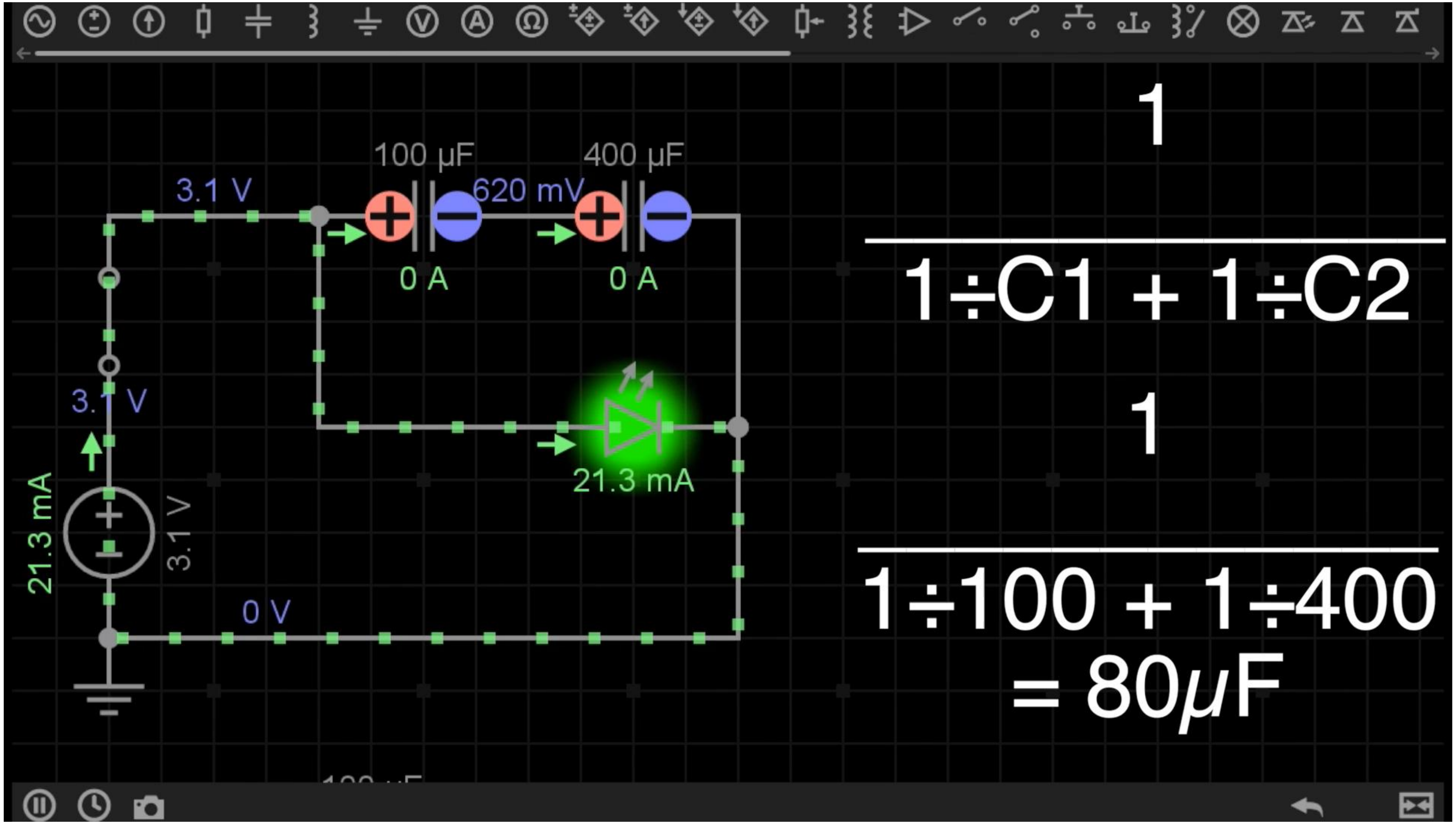






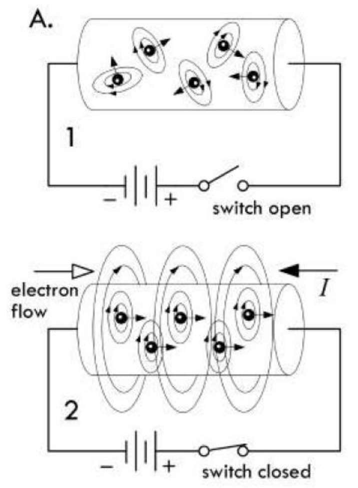
[What are Capacitors? - Electronics Basics 11]

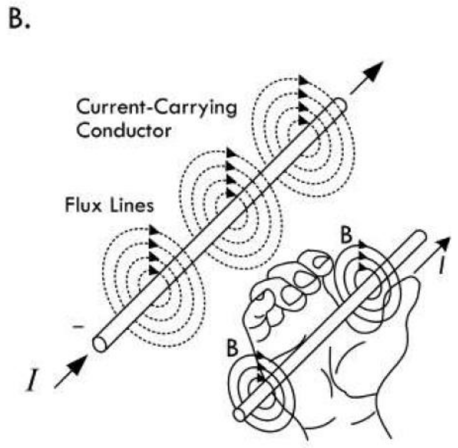
Capacitors – Series and Parallel

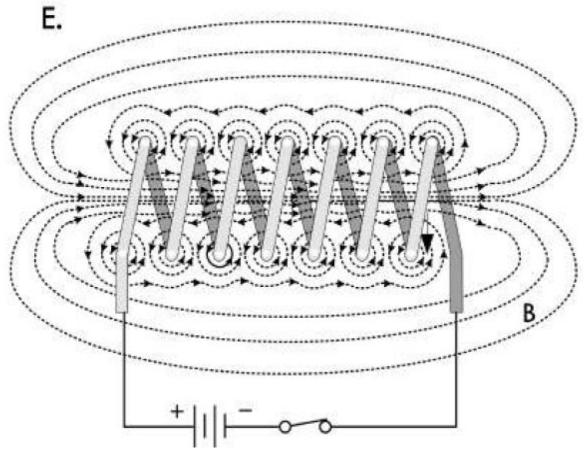


Inductance

Circular radiating magnetic fields can be generated about a wire any time current passes through it. When a current flows through a wire this generates a magnetic field which creates a magnetic flux.







- **Single moving electron**

A moving electron produces a tiny magnetic field around its path (this is a result of electromagnetism, from Maxwell's equations).

- **Current in a straight wire**

In a wire, billions of electrons drift together. Their individual magnetic fields overlap and **add up to form a circular magnetic field** around the wire.

- **Wire bent into a loop/coil (inductor)**

When you bend the wire into a loop, the magnetic fields inside the loop **reinforce each other**. Wrapping the wire into many turns (a coil) **multiplies the effect**, creating a strong, organized magnetic field inside the coil.

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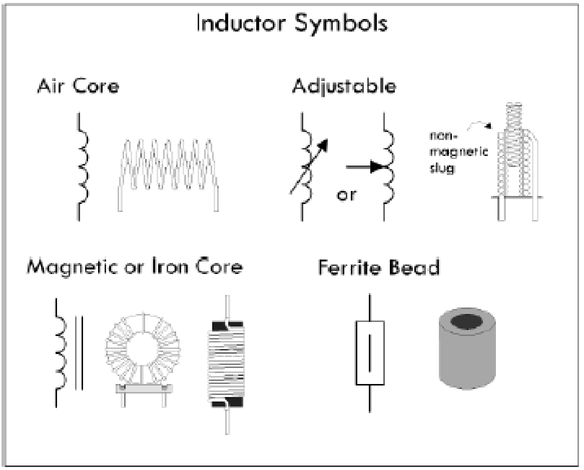
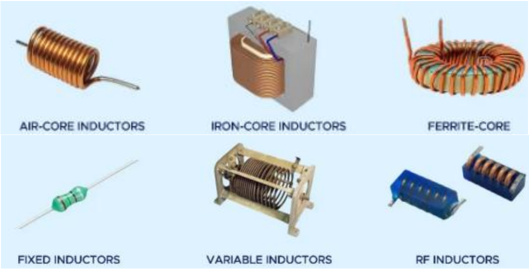
Book: Make:Electronics – Experimetn 24



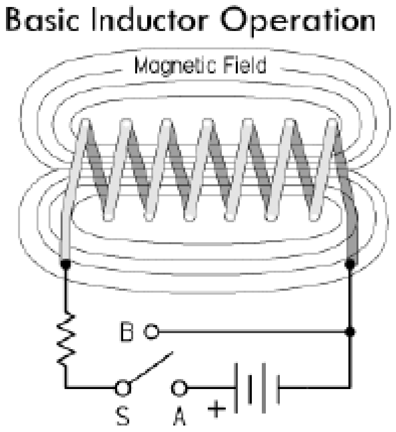
Inductor

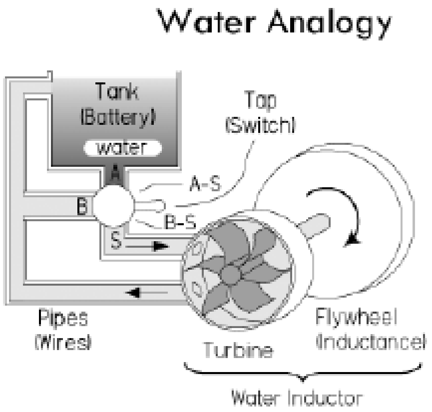


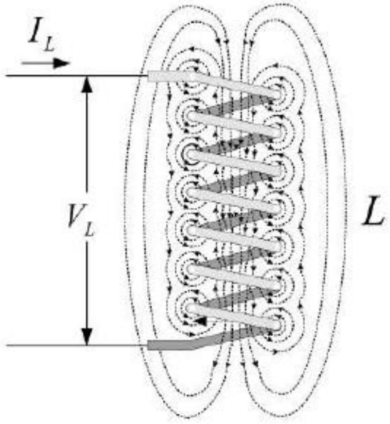
An **inductor** is the element that is capable of **storing or buffering magnetic flux**. In the simplest case, an inductor consists of a **number of copper windings**. They are capable of generating large concentrations of magnetic flux, and they are likewise capable of experiencing a large amount of **self- induction** during times of great change in current.

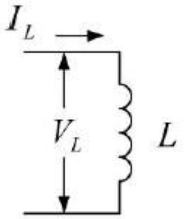
When a varying current flows through a self-inductance (di/dt), this results in a change in the flux. A changing flux translates into an **induced voltage**.

An inductor acts like a **time- varying current- sensitive resistance**. It only “resists” during changes in current; otherwise (under steady- state dc conditions), it passes current as if it were a wire.









$$V_L = L\frac{dI_L}{dt}$$

$$I_L = \frac{1}{L}\int V_L dt$$

L - the inductance - unit **Henry (H)**

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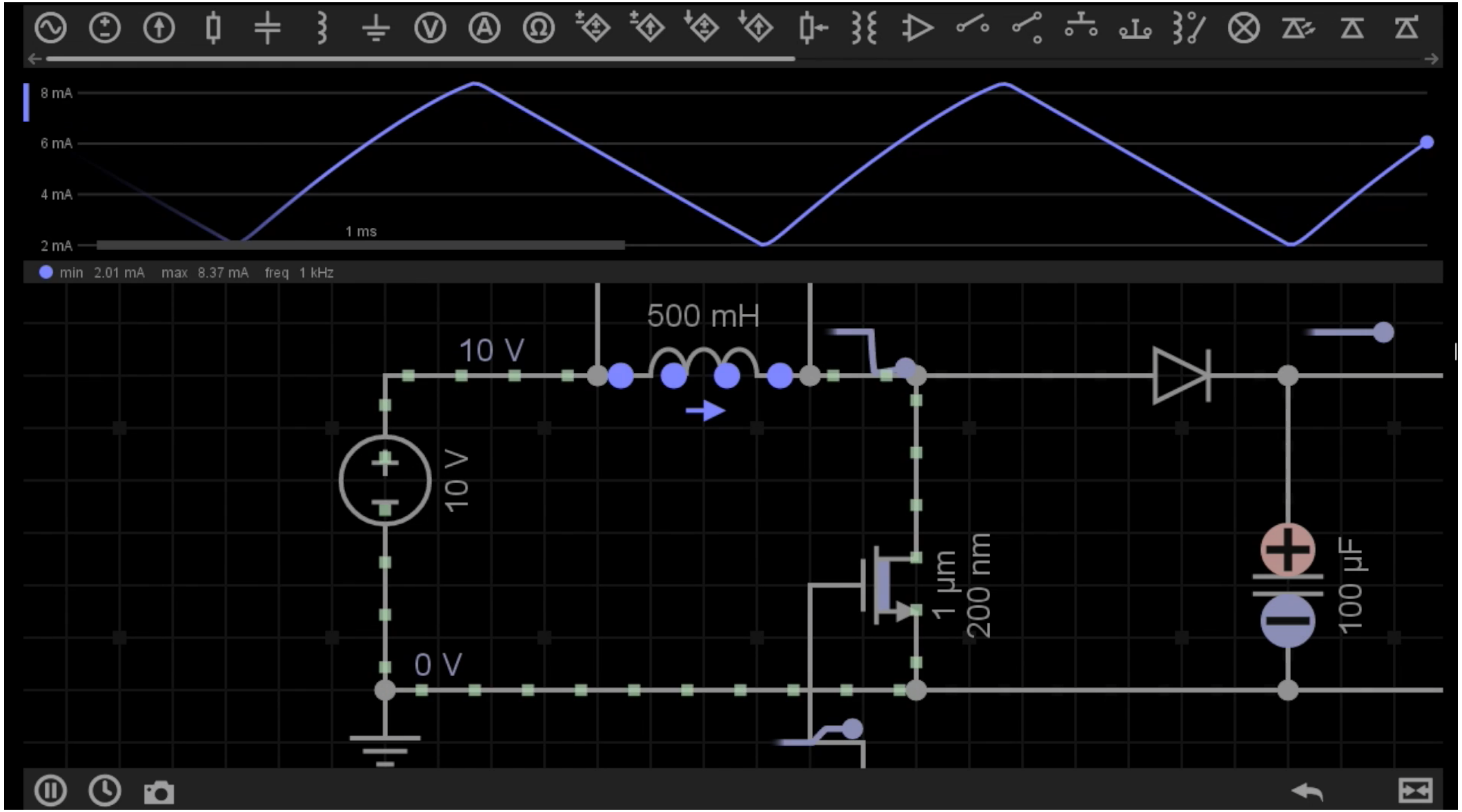
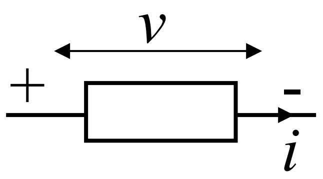
Inductance



[What is an Inductor? EASY! - Electronics Basics 21 - YouTube]

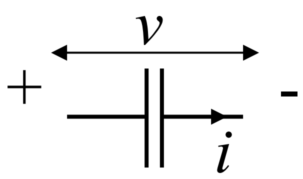
Element equations

resistor



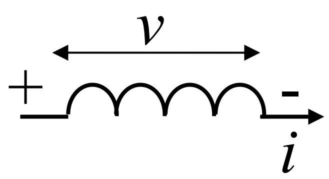
$$v = i \cdot R \qquad i = \frac{v}{R}$$

capacitor



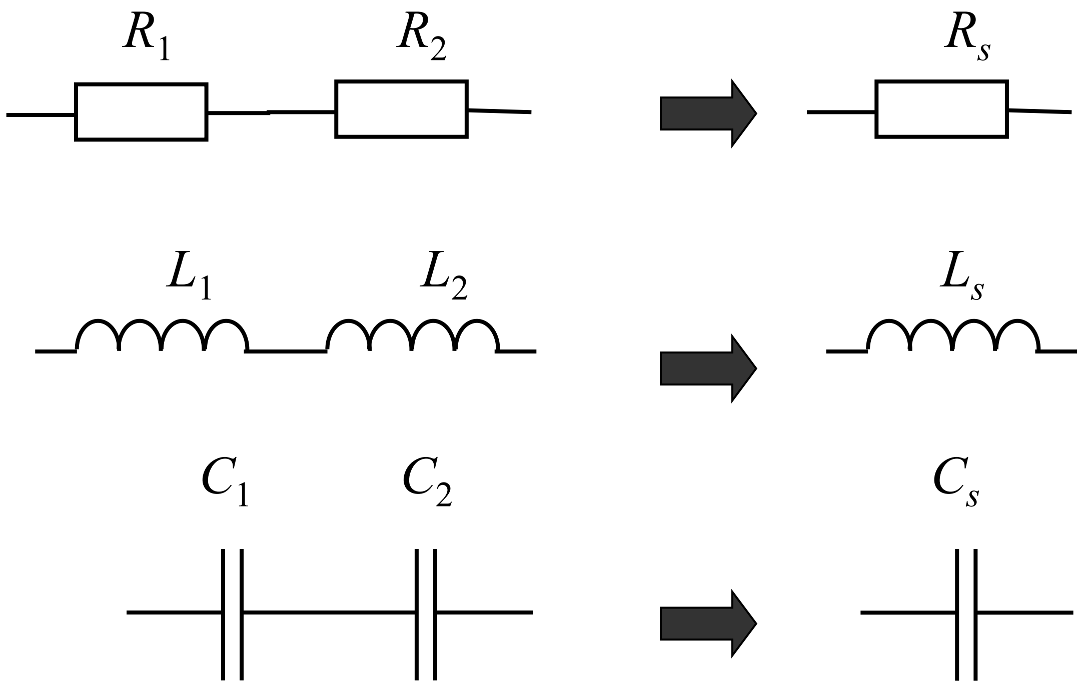
$$v = \frac{1}{C}\int i\,dt \qquad i = C\frac{dv}{dt}$$

inductor



$$v = L\frac{di}{dt} \qquad i = \frac{1}{L}\int v\,dt$$

Series connection

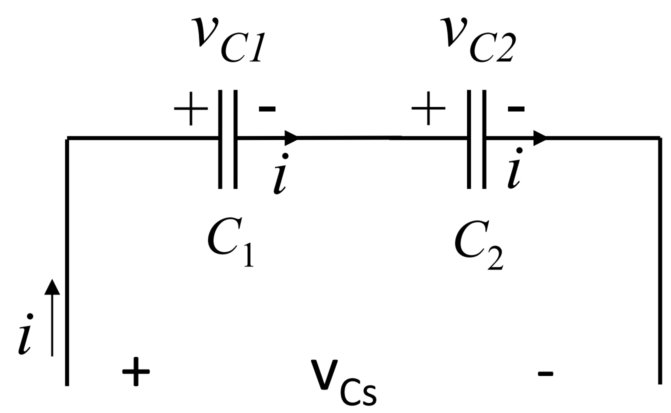


$$R_s = R_1 + R_2$$

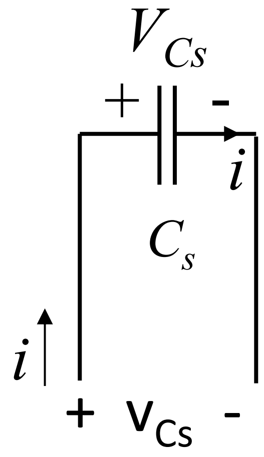
$$L_s = L_1 + L_2$$

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2}$$

What about the series Cs?



$$\equiv$$



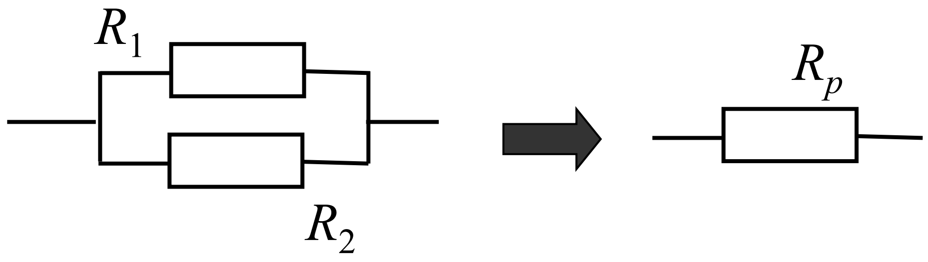
$$v_{Cs} = v_{C1} + v_{C2}$$

$$= \frac{1}{C_1}\int i\,dt + \frac{1}{C_2}\int i\,dt$$

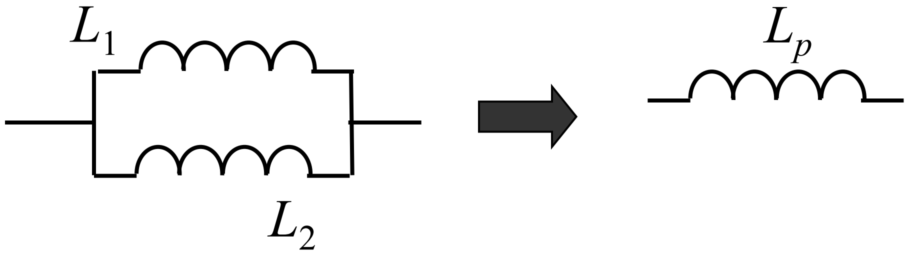
$$v_{Cs} = \frac{1}{C_s}\int i\,dt$$

$$\frac{1}{C_s}\int \cancel{i\,dt} = \frac{1}{C_1}\int \cancel{i\,dt} + \frac{1}{C_2}\int \cancel{i\,dt} \quad \rightarrow \quad \frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2}$$

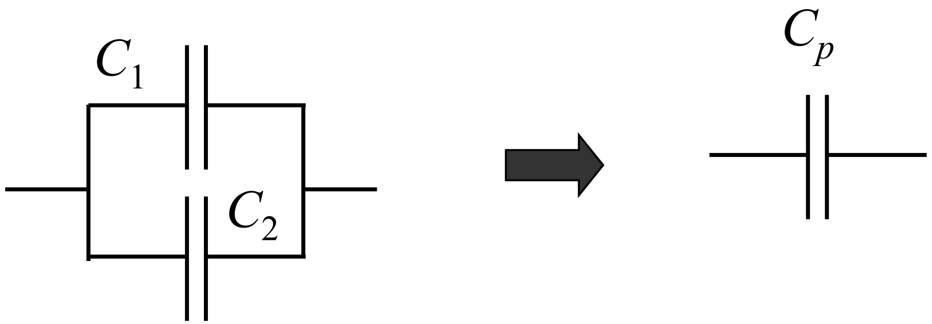
Parallel connection



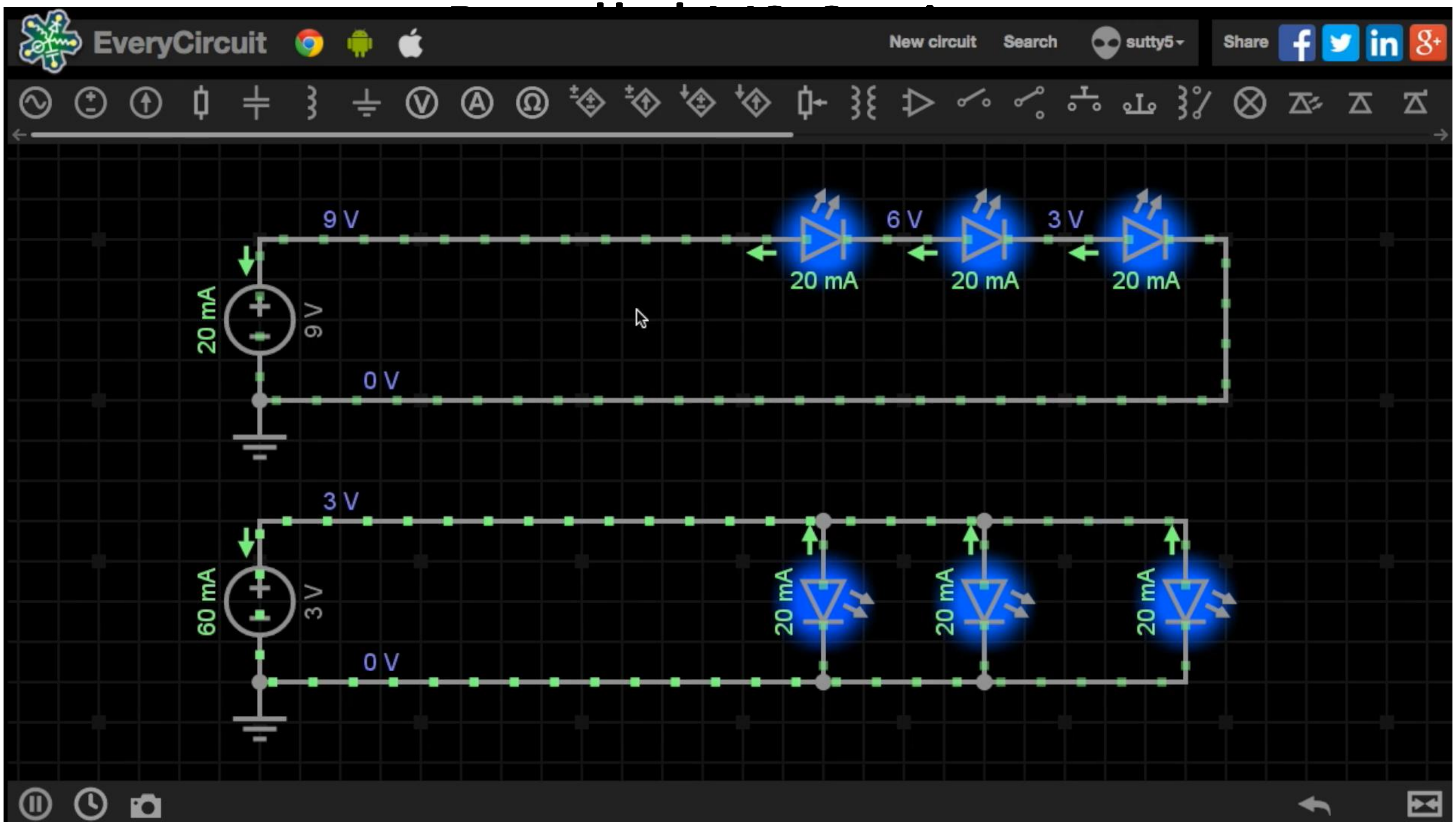
$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$$



$$\frac{1}{L_p} = \frac{1}{L_1} + \frac{1}{L_2}$$



$$C_p = C_1 + C_2$$



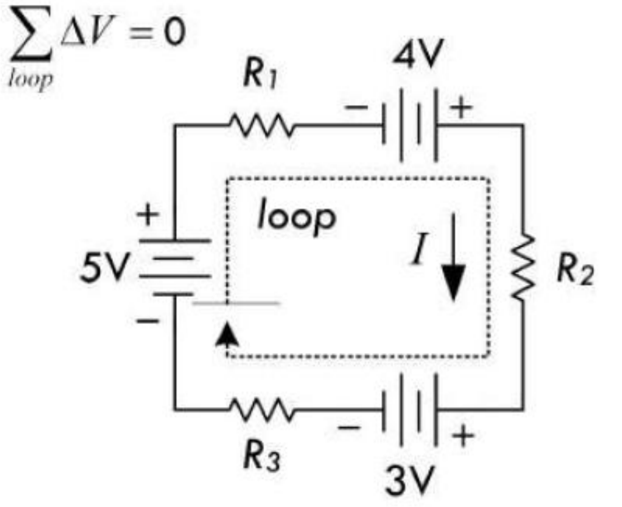
[Series and Parallel Circuits (Interactive!): Electronics Basics 5]

Kirchhoff’s Laws

Kirchhoff’s laws provide the most **general method for analyzing circuits**. These laws work for either **linear** (resistor, capacitors, and inductors) or **nonlinear elements** (diodes, transistors, etc.), no matter how complex the circuit gets.

Kirchhoff’s Voltage Law (or Loop Rule): The algebraic sum of the voltages around any loop of a circuit is zero:

$$\sum_{\text{closed path}} \Delta V = V_1 + V_2 + \cdots + V_n = 0$$

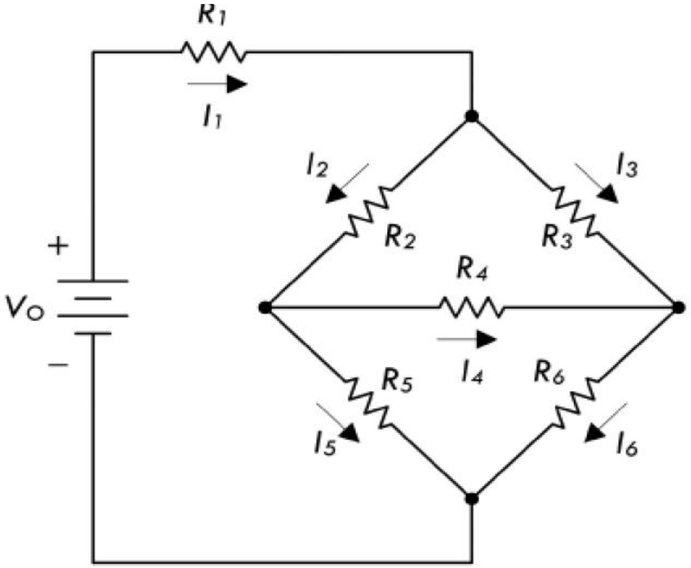


$$5V - IR_1 + 4V - IR_2 - 3V - IR_3 = 0$$

Kirchhoff’s Current Law (or Junction Rule): The sum of the currents that enter a junction equals the sum of the currents that leave the junction:

$$\sum I_{\text{in}} = \sum I_{\text{out}}$$

Kirchhoff’s current law is a statement about the conservation of charge flow through a circuit: at no time are charges created or destroyed.



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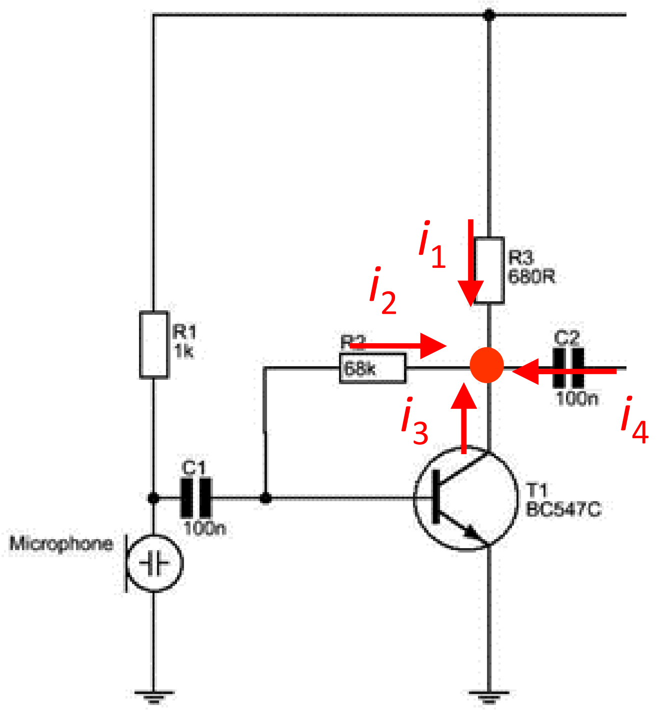
Kirchhoff's laws

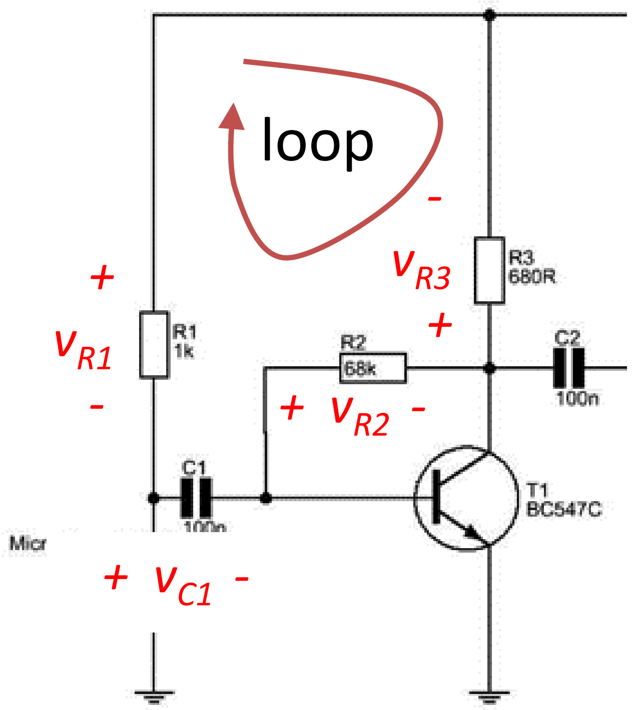
- 1st law: Kirchhoff's Current Law (KCL): $\sum i_{node} = 0$



$$i_1 + i_2 + i_3 + i_4 = 0$$

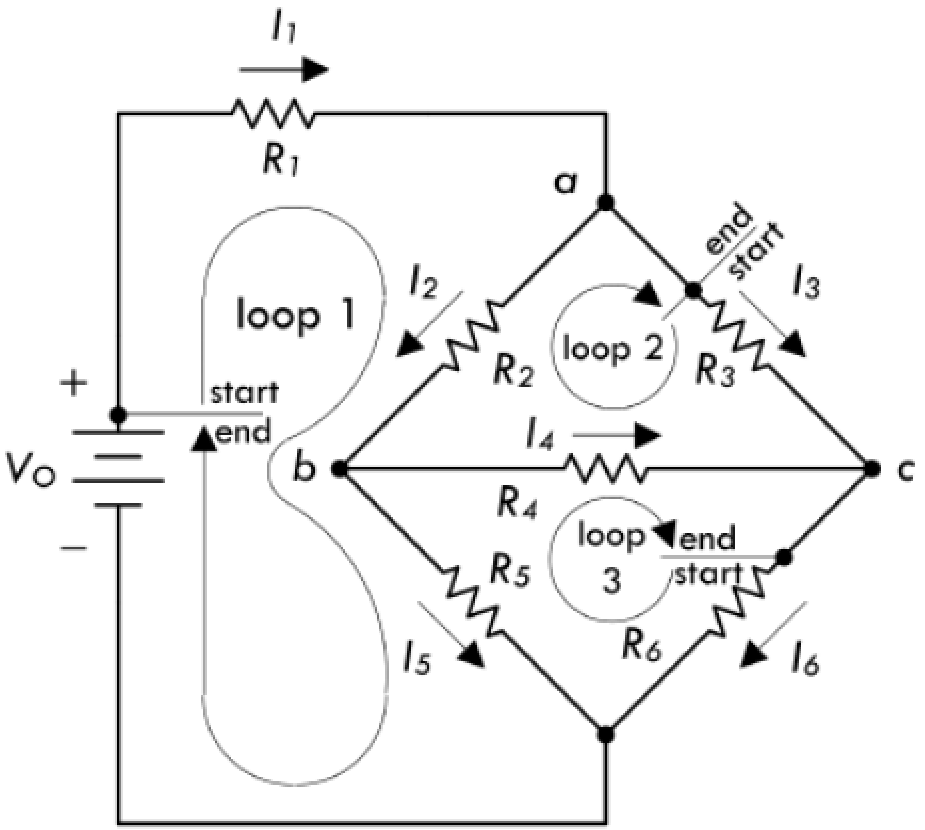
Kirchhoff's laws

- 2nd law: Kirchhoff's voltage law (KVL): $\sum v_{loop} = 0$



$$v_{R1} + v_{R3} + v_{R2} + v_{C1} = 0$$

Kirchhoff's Laws - example



Equations resulting after applying Kirchhoff's current law:

$I_1 = I_2 + I_3$ (at junction a)

$I_2 = I_5 + I_4$ (at junction b)

$I_6 = I_3 + I_4$ (at junction c)

Equations resulting after applying Kirchhoff's voltage law:

$V_0 - I_1R_1 - I_2R_2 - I_5R_5 = 0$ (around loop 1)

$-I_3R_3 + I_4R_4 + I_2R_2 = 0$ (around loop 2)

$-I_6R_6 + I_5R_5 - I_4R_4 = 0$ (around loop 3)

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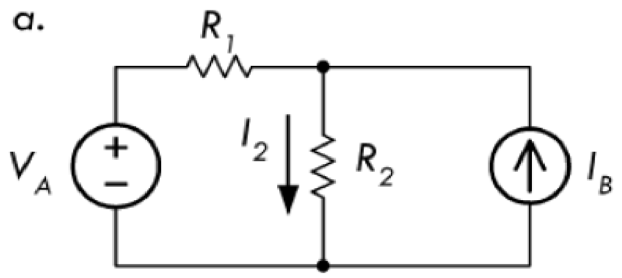
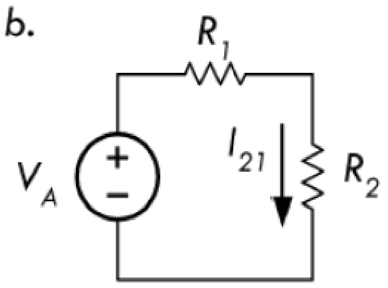
Superposition Theorem

The **superposition theorem** is an important concept in electronics that is useful whenever **a linear circuit** contains **more than one source**.

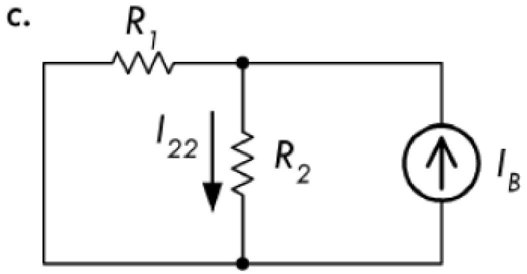
> ***Superposition theorem:*** *The current in a branch of a linear circuit is equal to the sum of the currents produced by each source, with the other sources set equal to zero.*



$$I_2 = I_{21} + I_{22} = \frac{V_A - I_B R_1}{R_1 + R_2}$$



$$I_{21} = \frac{V_A}{R_1 + R_2}$$



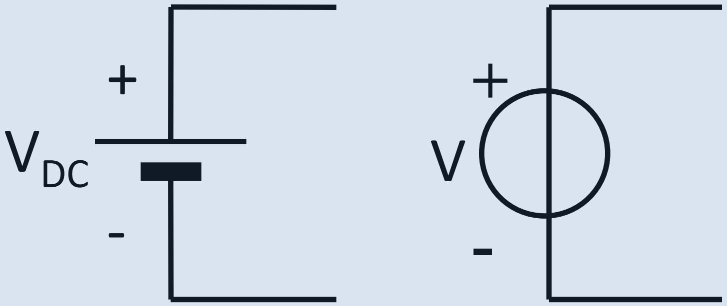
$$I_{22} = \frac{I_B R_1}{R_1 + R_2}$$

Be aware: that the superposition should not be applied to nonlinear circuits.

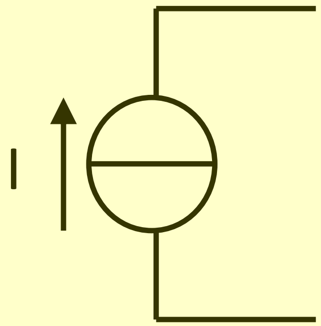
Thevenin’s and Norton’s Theorems

READ subchapet 2.19

Active elements

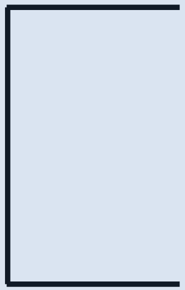


voltage source



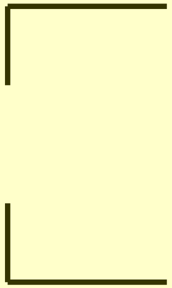
current source

If V = 0:



short circuit

If I = 0:

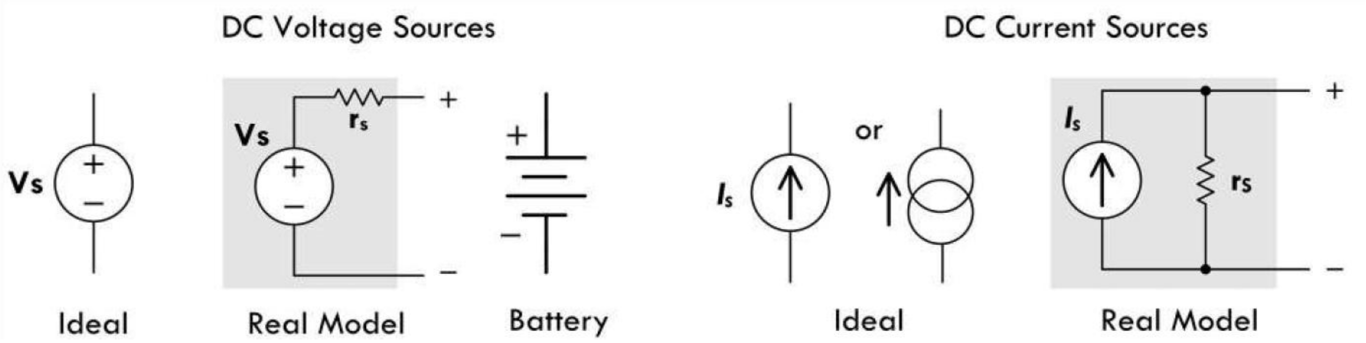


open circuit

Voltage and current sources

An **ideal voltage source** is a two- terminal device that maintains **a fixed voltage across its terminals**. If a variable load is connected to an ideal voltage source, the source will maintain its terminal voltage regardless of changes in the load resistance.
A **real voltage source** resembles an ideal voltage source with a small series internal resistance or source resistance rs, which is a result of the imperfect conducting nature of the source

An **ideal current source** provides the same amount of source current IS at all times to a load, regardless of load resistance changes. This means that the **terminal voltage will change** as much as needed as the load resistance changes in order to keep the source current constant.
This **internal resistance**, in real current source, which is usually very large, tends to reduce the terminal current, the magnitude of which depends on its value and the amount of current that is drawn from the source



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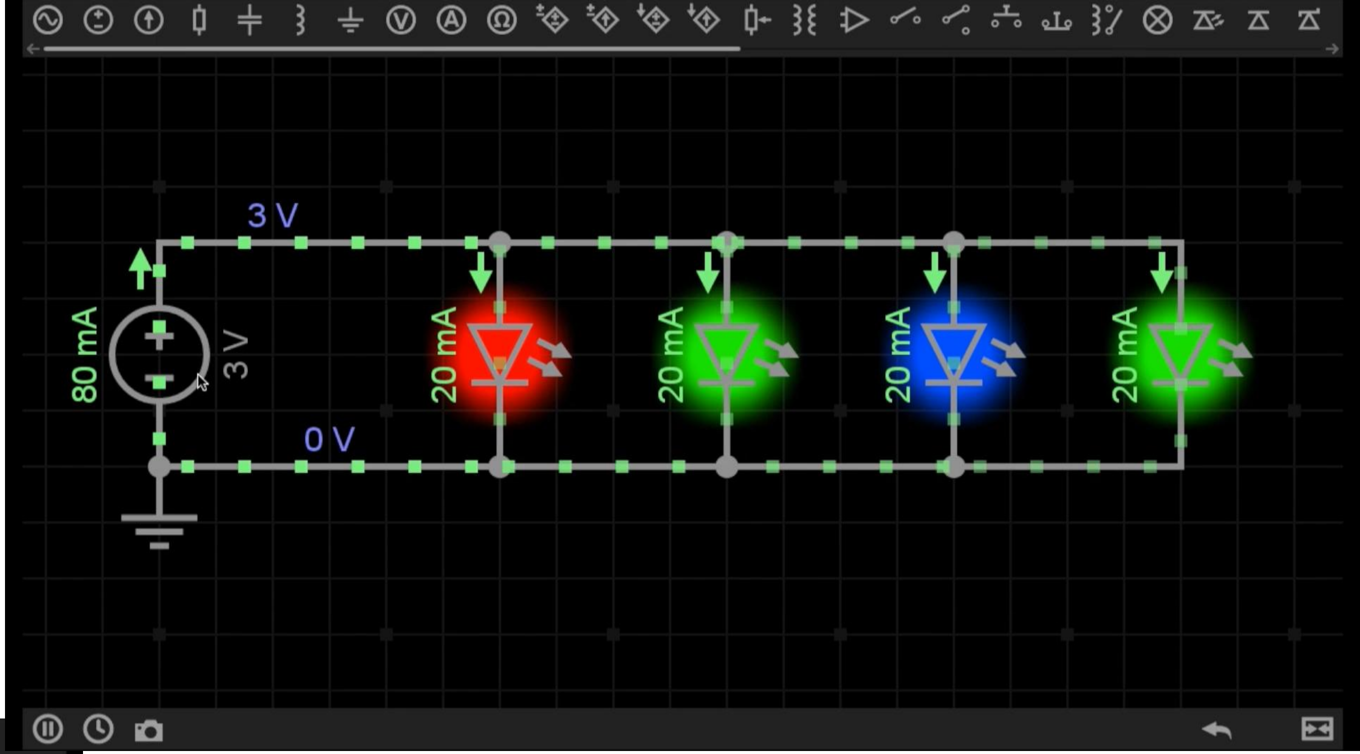
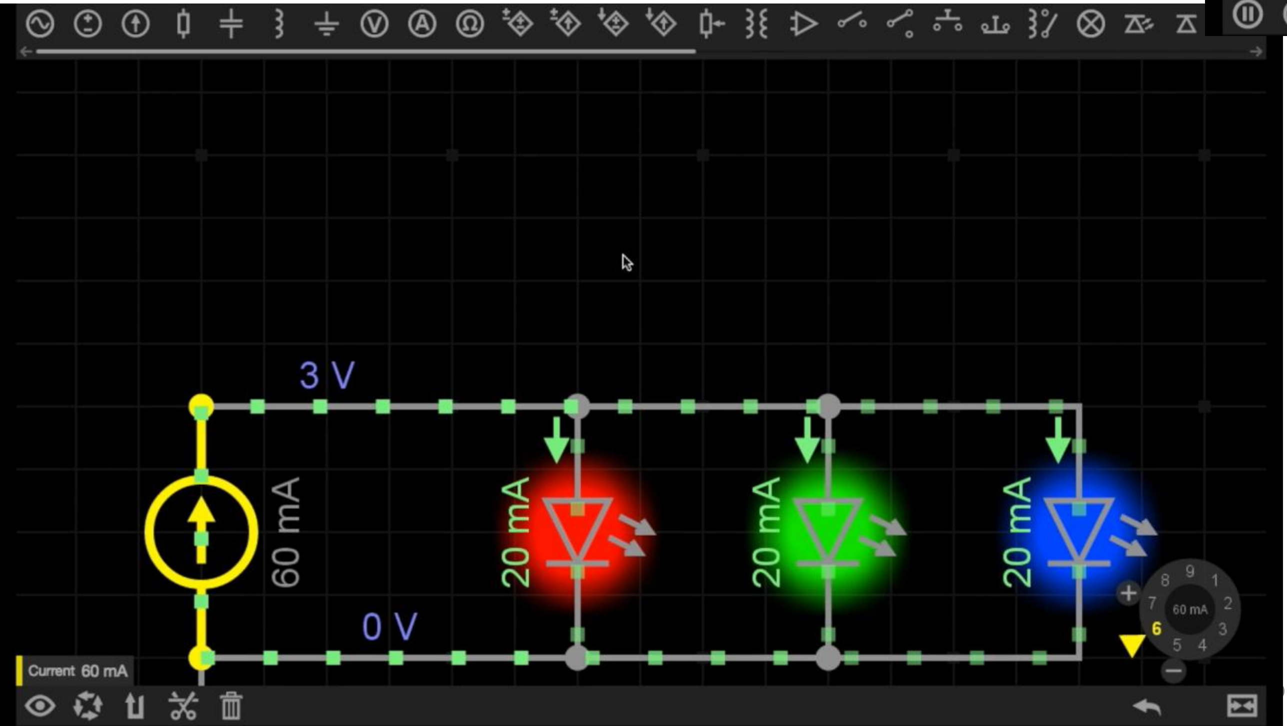
Voltage and



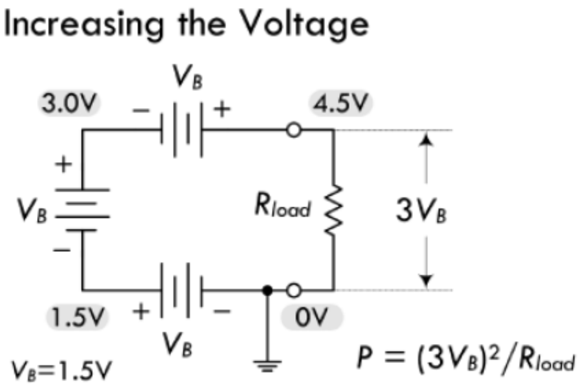


[Constant Current Sources (Interactive!) - Simply Electronics Basics 9]

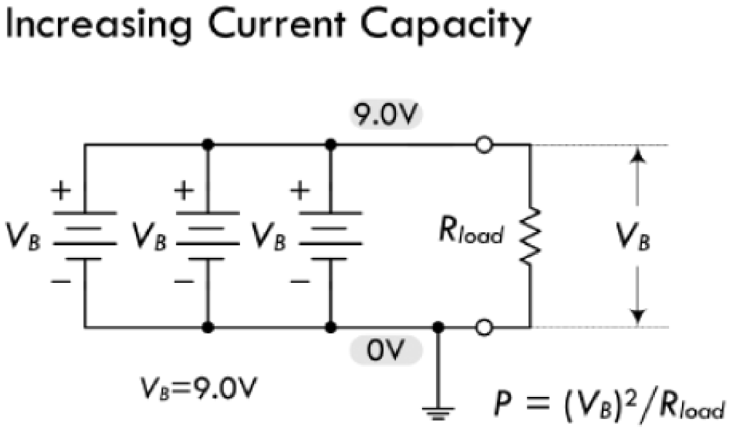
Voltage and current sources

The way how we **connect sources** dictates if we **increase the supply voltage** and/ or **increase the supply current** capacity.

To increase the supply voltage, batteries are placed **end to end or in series**; the terminal voltages of each battery **add together** to give a final supply voltage equal to the sum from the batteries.



To create a supply with **added current** capacity (increased operating time), batteries can be placed in parallel—positive terminals are joined together, as are negative terminals.



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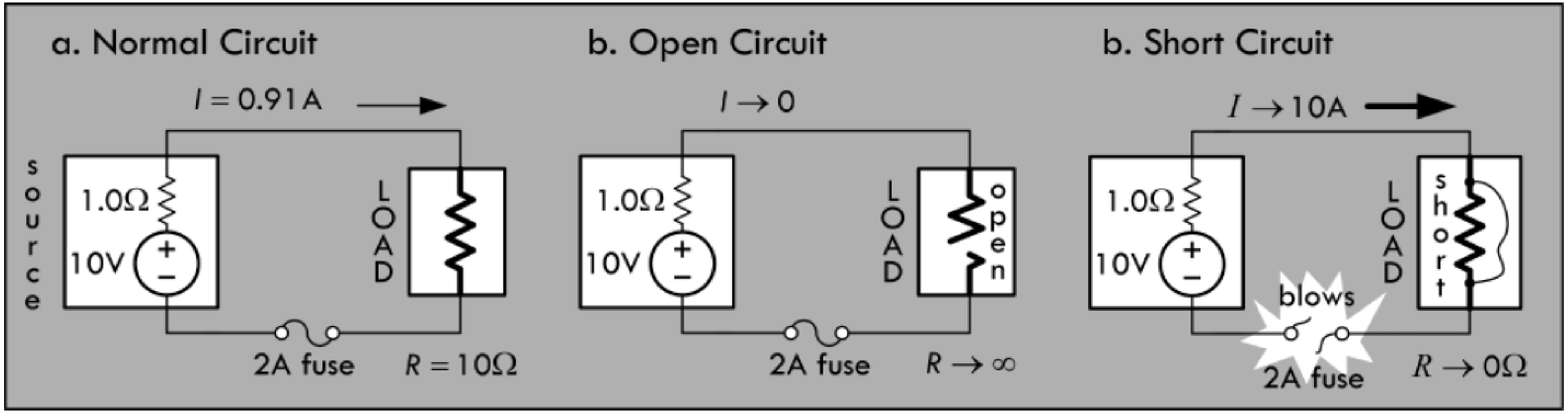
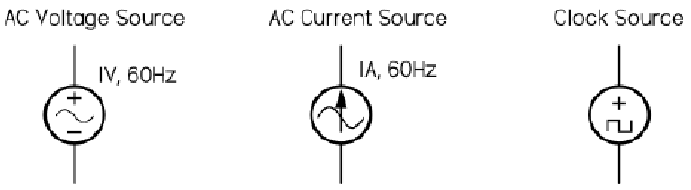
Open and Short Circuits

The most common problems (faults) in circuits are **open circuits and shorts**. A **short circuit** in all or part of a circuit causes excessive current flow. This may blow a fuse or burn out a component, which may result in an **open- circuit condition**.

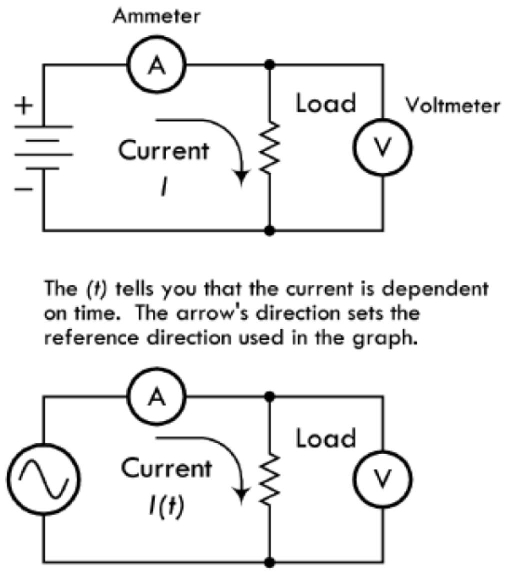


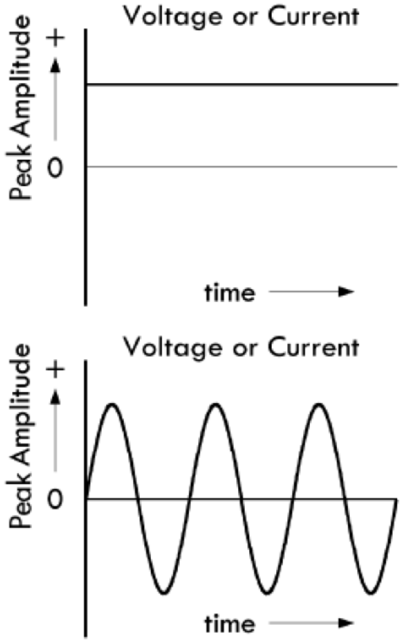


AC Circuits

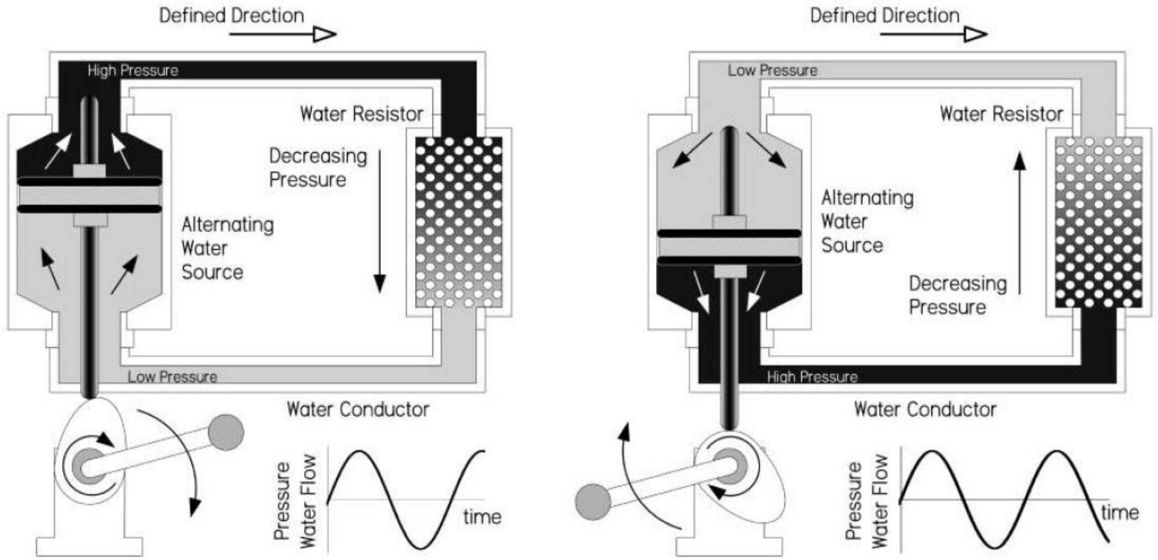
A circuit is a complete conductive path through which electrons flow from source to load and back to source. If the **source is dc**, electrons will flow in only one direction, resulting in a direct current (dc).

Another type of source that is frequently used in electronics is an **alternating source** that causes current to **periodically change direction**, resulting in an alternating current (ac).





Water analogy



Solving electronic networks

- Electronic problem concerning voltage, current, power, L, R, C
  - Draw schematic.
  - Write down appropriate KCL and KVL equation(s)
  - Fill in element equations
  - Bingo!