# ELL101: INTRODUCTION TO ELECTRICAL ENG.

## Basic Components of Electrical Circuits

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# SI Units

SI (System International) units: Official system of measurement of length, distance, weight, temperature, etc.

Prefixes:

| | |
|---|---|
| pico (p): $10^{-12}$ | tera (T): $10^{12}$ |
| nano (n): $10^{-9}$ | giga (G) : $10^{9}$ |
| micro ($\mu$): $10^{-6}$ | mega (M): $10^{6}$ |
| milli (m): $10^{-3}$ | kilo (k): $10^{3}$ |

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# SI Units

| *Quantity* | *Symbol* | *Unit* | *Abbreviation* |
|---|---|---|---|
| Energy | w | Joule | J |
| Power | P | watt | W |
| Charge | q | Columb | C |
| Current | i | Ampere | A |
| Voltage | v | Volt | V |
| Force | f | Newton | N |
| | | | |

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# Electricity

- Electricity is generated because of flow of electrical power or charges.
- Electrons are the particles which carry charge.
- So electricity is a result of accumulation or motion of numbers of electrons.
- Static electricity: Because of an imbalance between negative and positive charges on a surface/object. These charges can stay on the surface/object till they are discharged through some ways. Example: Charging of a capacitor and when you short-circuit both its terminals, there is lightning/spark.
- Dynamic electricity: Because of steady flow of electrons between nodes. A conductor of electricity is needed for the same.

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## Current

- Electric current is the rate of flow of electric charge through a point or surface.

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

- $q$ denotes charge.
- Charge on 1 electron = $1.602 \times 10^{-19}$ C

- The unit of current is the ampere (A). Note that

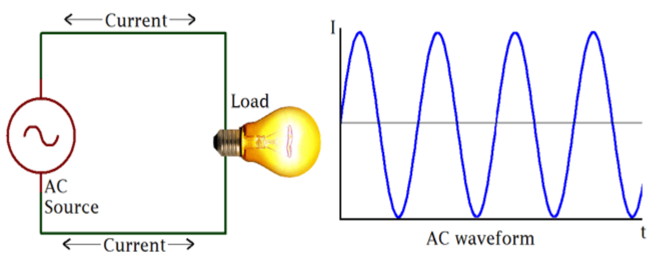
1 ampere = 1 coulomb/second





## Types of Electric Current (AC)

- Alternating Current (AC): the movement of electric charge periodically reverses direction.

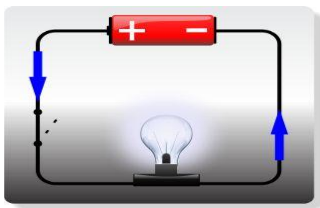



Source: https://circuitdigest.com/tutorial/ac-circuit-theory

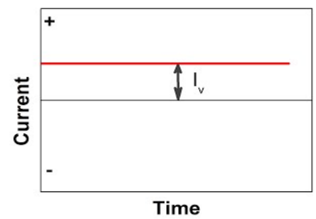
- Electric power is delivered in the form of AC to our houses and industries.

# Types of Electric Current (DC)

- Direct current (DC): DC is an electric current that is uni-directional, hence the flow of charge is always in the same direction.



Source: https://www.pinterest.com/pin/266275396691168285/




Source: https://sites.google.com/site/theme5electricityinthehome/alternating-current

- Battery is a source of DC, further, DC may be obtained from an AC supply by using a rectifier

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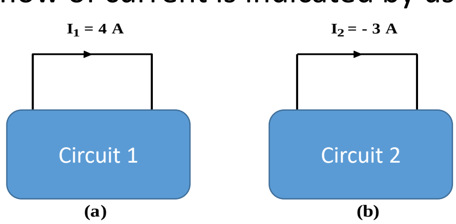
# Conventions for Direction of Current Flow

- In the circuit theory analysis, it is important to know the correct direction of flow of current.
- The direction of flow of current is indicated by using an arrow.




- In Fig a, current $I_1$ of 4A flows from left to right but in Fig b, $I_2$ of 3A flows from right to left.

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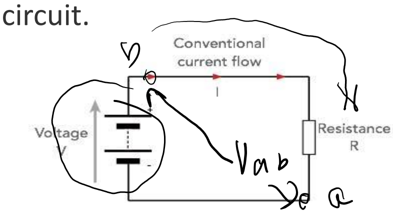
# Voltage

- Voltage: It is the difference in electric potential between two points.
- Voltage can be considered as the pressure that forces the charged electrons to flow in an electrical circuit.




Source: https://www.electronics-notes.com/articles/basic_concepts/voltage/what-is-voltage-basics-tutorial.php

- Voltage is also called electromotive force (emf).
- Suppose one coulomb of charge is located at point b and one joule of energy is required to move the charge to point a. Then we say that $V_{ab}$ = 1 volt = 1 joule/coulomb = 1 newton.meter/coulomb.

$$v = \frac{dw}{dq}$$

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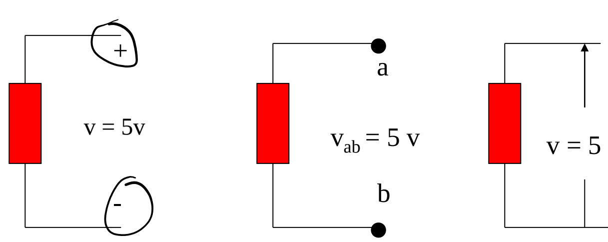
# Voltage

Similar to the current, we must assume a direction/polarity for the voltage.
For example, see the three diagrams below.




Each of the above gives the same information.

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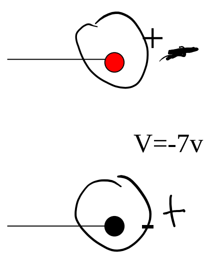
# Sign Convention for Voltage

- Consider the following figure:




The negative sign for 7 v indicates that if the red lead of a voltmeter is placed on + terminal and the black lead on the – terminal the meter will read downscale or –7v. A digital meter would read –7 v. What about an analog meter?

We need to keep in mind that we assume a polarity for the voltage. When we solve the circuit for the voltage, we may find that the actual polarity is not the polarity we assumed.

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# Definitions

- Electric Field Strength: Around an electric charge is a region of influence called the electric field. Electric field strength is the force experienced by a unit positive charge in the field

$$\vec{f} = q\vec{E} \qquad \vec{E} = -\frac{dv}{dl}$$

- Magnetic Flux Density: Around a moving charge or current is a region of influence called the magnetic field. The force exerted by a charge moving with a certain velocity due to magnetic flux density

$$\vec{f} = q\vec{u} \times \vec{B}$$

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# Electrical Power and Energy

Instantaneous Power

$$p = \frac{dw}{dt} = \frac{dw}{dq}\frac{dq}{dt} = v\ i$$

Total Energy

$$w = \int p\ dt = \int v\ i\ dt$$

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# Example 1

The "electron gun" of a cathode-ray tube provides a beam of high-velocity electrons.

(a) If the electrons are accelerated through a potential difference of 20,000 V over the distance of 4 cm (as shown in Figure), calculate the average field strength.

(b) Calculate the power supplied to a beam of 50 million billion electrons per second.

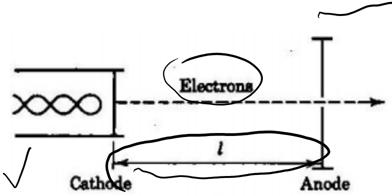


**Figure: Current and power**

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# Example 1

(a) By definition, $\mathcal{E} = -dv/dl$ or

$$\mathcal{E}_{av} = \frac{\Delta v}{\Delta l} = \frac{20{,}000}{0.04} = 5 \times 10^5 \text{ V/m}$$

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# Example 1

(a) By definition, $\mathcal{E} = -dv/dl$ or

$$\mathcal{E}_{av} = \frac{\Delta v}{\Delta l} = \frac{20{,}000}{0.04} = 5 \times 10^5 \text{ V/m}$$


(b) By definition, $i = dq/dt$ or

$$i = \frac{\text{charge}}{\text{electron}} \times \frac{\text{electrons}}{\text{second}}$$

$$= 1.6 \times 10^{-19} \times 50 \times 10^6 \times 10^9 = 0.008 \text{ A}$$

By Eq. 1-8, the power is

$$p = vi = 2 \times 10^4 \times 8 \times 10^{-3} = 160 \text{ W}$$

*Note:* In calculations, enter all values in SI units. Only in the results are units shown.

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# Electrical Power and Energy

- In any closed electric circuit, there are few elements which supply power and there are few elements which absorb the power. Further,

**Power supplied=Power absorbed**

- Stated another way, we can say that the law of conservation of energy must hold. Therefore, in any electric circuit the algebraic sum of the power must be zero.

$$\sum P_i = 0$$

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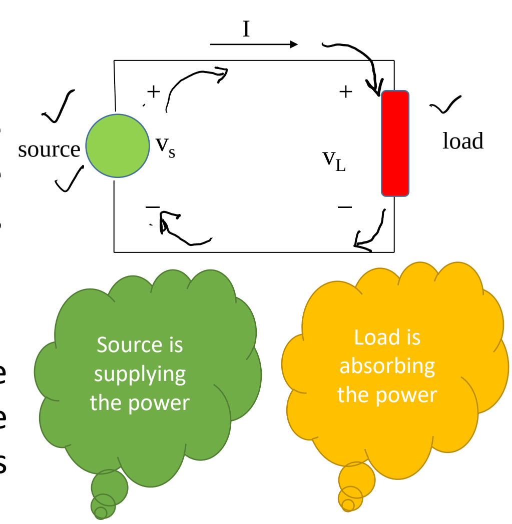
# Sign Convention for Power

- Power supplied

  If the assumed direction of the current leaves the assumed positive polarity of the voltage, power is supplied.

- Power absorbed

  If the assumed direction of the current enters the assumed positive polarity of the voltage, power is absorbed.

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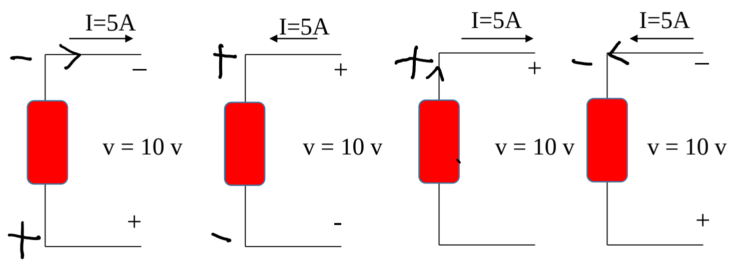
# Electrical Power Calculation Examples

Let us consider the following examples:




(a) P = 50W absorbed

(b) P = 50W absorbed

(c) P = -50W absorbed

(d) P = -50W absorbed

OR

P=50W supplied

P=50W supplied

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# Circuit Elements

- Passive elements: They cannot generate energy. Examples: resistors, capacitors and inductors. Capacitors and inductors can store energy but cannot generate energy.

- Active elements: They can generate energy.

Examples: Power supplies, batteries, operational amplifier.

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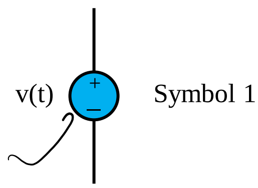
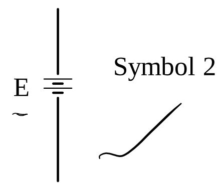
## Ideal Voltage Source

- An ideal voltage source has a constant voltage across its terminals, despite of the load connected to the terminals.
- The ideal voltage source can supply an arbitray amount of current and power.
- Standard symbols of the ideal voltage source:

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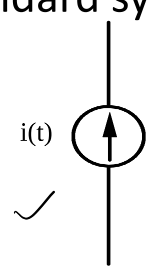
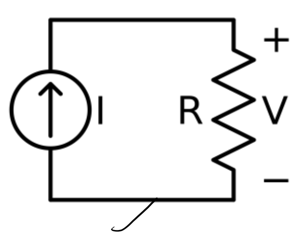
## Ideal Current Source

- An ideal current source provides a constant current, to any load.
- The ideal current source can generate any amount of voltage and supply arbitrary power to load.
- Standard symbol of the ideal current source:

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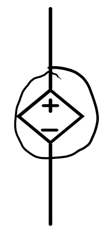
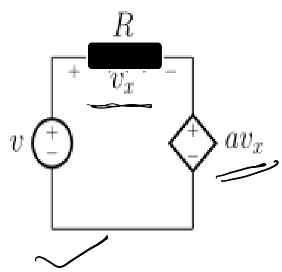
# Dependent Voltage Source

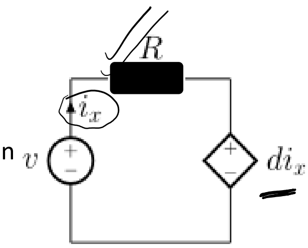
The voltage of a dependent voltage source depends upon a voltage or current at some other place in the circuit.



The voltage of a dependent voltage source depends upon the voltage drop at the circuit element.




The voltage of a dependent voltage source depends upon the voltage drop at the circuit element.

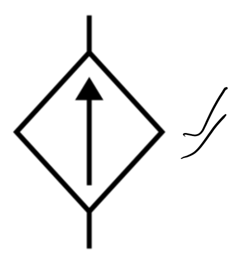




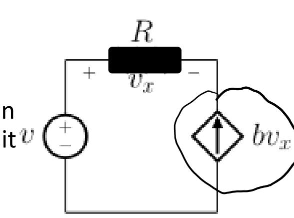



# Dependent Current Source

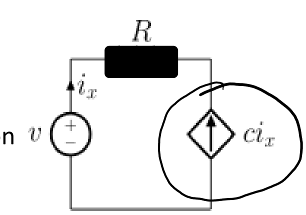
The current of a dependent current source depends upon a voltage or current at some other place in the circuit.



The current of a dependent current source depends upon the voltage drop at the circuit element.

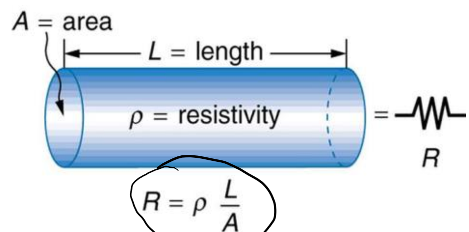



The current of a dependent current source depends upon the current in the circuit element.



# Resistance

- Resistance is a measure of the opposition to current flow in an electrical circuit.
- Resistance is measured in ohms, symbolized by the Greek letter omega (Ω).



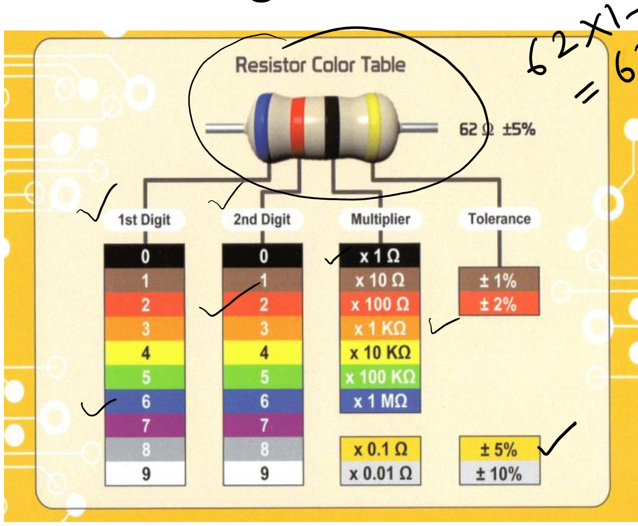

Ω

Source: https://courses.lumenlearning.com/boundless-physics/chapter/resistance-and-resistors/





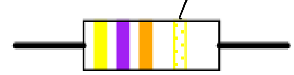
# Color Coding of Resistance




$62 \times 1\Omega$
$= 62\Omega$
$\pm 5\%$

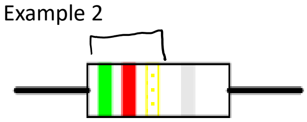
Example 1

Gold



Yellow-Violet-Orange-Gold
47 kΩ with a tolerance of +/- 5%

Example 2



Green-Red-Gold-Silver
5.2 Ω with a tolerance of +/- 10%

Source: https://www.electronicsforu.com/electronics-projects/resistor-colour-code

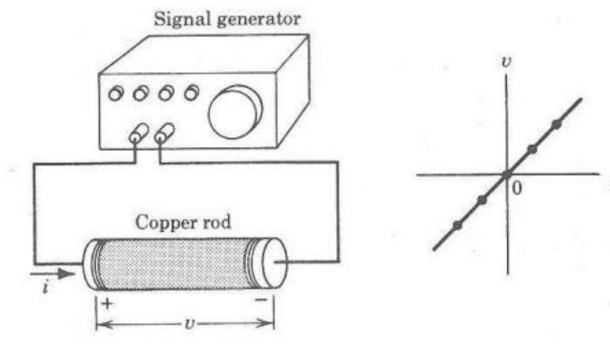
# Experimental Laws

$V \propto I$

- Resistance: Ohms Law

$$v = Ri$$

$$i = Gv$$

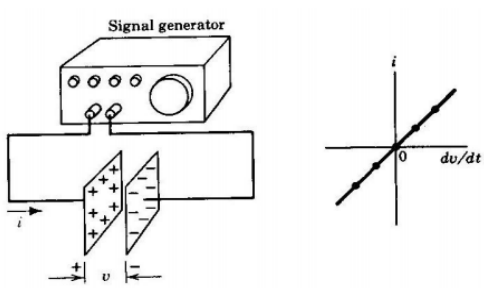





# Capacitance

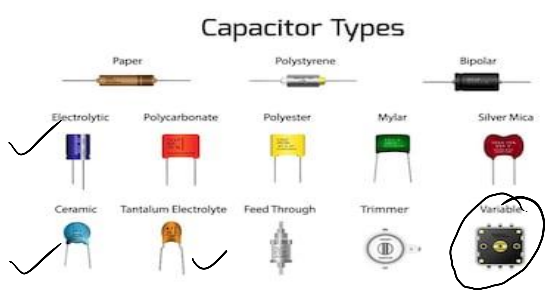
$$i = C\frac{dv}{dt} = \frac{dq}{dt}$$

$$q = C\,v$$

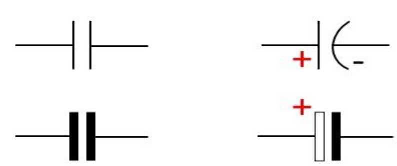



| Unit | Multiplier | Example |
|---|---|---|
| Farad (F) | 1 | 1 F |
| Milifarad (mF) | $10^{-3}$ | 12 mF = 0.012 F |
| Microfarad (μF) | $10^{-6}$ | 12 μF = 0.000012 F |
| Nanofarad (nF) | $10^{-9}$ | 12 nF = 0.000000012 F |
| Picofarad (pF) | $10^{-12}$ | 12 pF = 0.000000000012 F |

Source: https://binaryupdates.com/what-is-capacitor/




Source: https://depositphotos.com/191130622/stock-illustration-group-of-capacitors-types-isolated.html

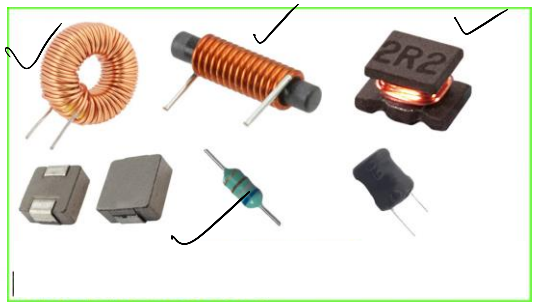



(a) Unpolarized (b) Polarized

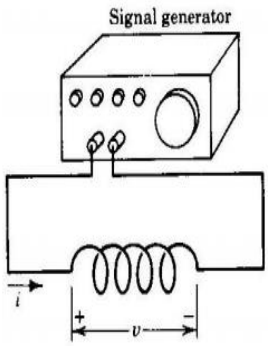
Source: https://binaryupdates.com/what-is-capacitor/

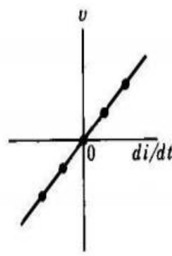
# Inductance

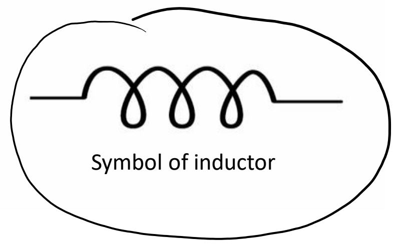
$$v = L\frac{di}{dt}$$



Source: http://www.electronicsandyou.com/inductor-basics-types-formula-symbol-unit-uses-function.html

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# Example 2

A current varied as a function of time as shown in Figure. Predict and plot the voltage produced by this current flowing in an initially uncharged 1 μF capacitor.

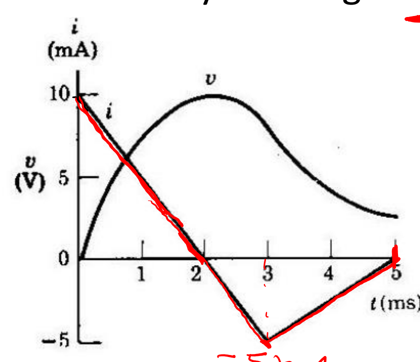
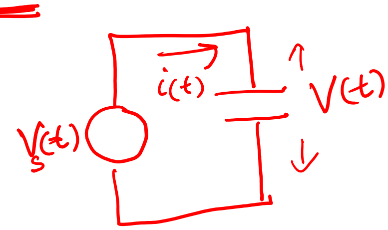



Figure: Current-voltage relations in a capacitor

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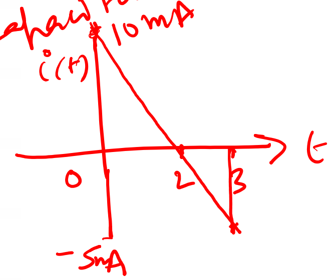
# Example 2

uncharged capacitor

For an ideal capacitor, $i = C\,dv/dt$.

$$\therefore v = \frac{1}{C}\int_0^t i\,dt + V_0 = 0$$




For $0 < t < 3$ ms, $V_0 = 0$ and

$$i = 10 \times 10^{-3} - (15 \times 10^{-3}/3 \times 10^{-3})t$$
$$= 0.01 - 5t$$

$$v(t) \quad \therefore v = \frac{1}{10^{-6}}\int_0^t (0.01 - 5t)\,dt + 0$$

$$v(t) = 10^6(0.01t - 2.5t^2), \text{ a parabola}$$

At $t = 2$ ms, for example,

$$v = 10^6(0.01 \times 2 \times 10^{-3} - 2.5 \times 4 \times 10^{-6})$$
$$= 20 - 10 = 10 \text{ V}$$

A similar calculation for $3 < t < 5$ ms (the voltage at 3 ms is 7.5 V) yields the curve shown.

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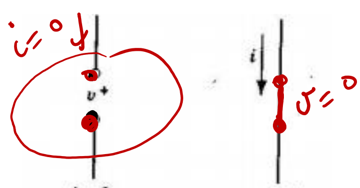
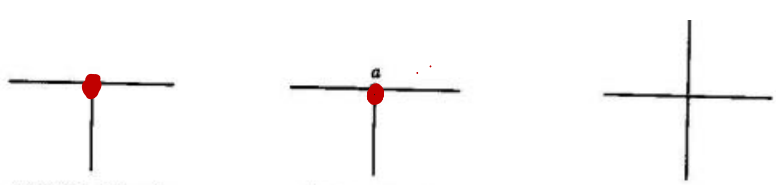
# Circuit Diagram Convention I




$i = 0$
for any $v$
(a)Open circuit

$v = 0$
for any $i$
(b) Short circuit




(a) Unlabeled node (b) Labeled node (c) No electrical connection

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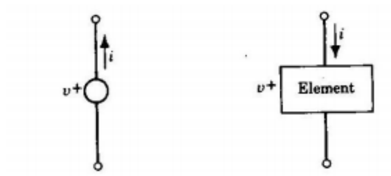
# Circuit Diagram Convention II

Passive element Total energy delivered to it from the rest of the circuit is always positive or zero

Active element The net energy supplied by it can be positive




(a) Active element (source) (b) Passive element

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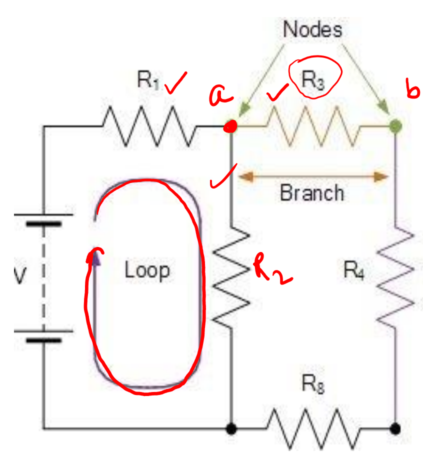
# Circuit Diagram Convention III

- Branch
  - Path containing one or more elements that connects two nodes
- Node
  - Terminal common to two or more branches of a circuit
- Loop
  - Closed path progressing from node to node and returning to the starting node.




Source: https://www.thepowerprofessor.com/definition-of-electric-circuit/

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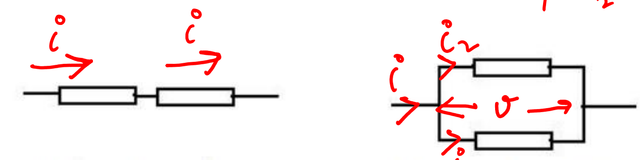
# Circuit Elements I

$i_1 + i_2 = i$



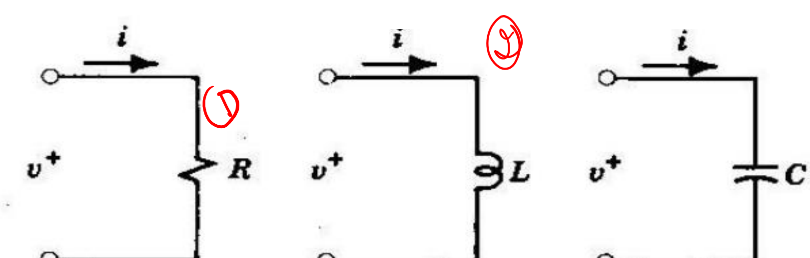

Series Connection (Component carry the same current)

Parallel Connection (components are subject to same voltage)

Behavior of a circuit component is described in term of a voltage current relation called V-I characteristic at the terminals of the component



# Circuit Elements II




$v = Ri$ $\qquad$ $v = L\dfrac{di}{dt}$ $\qquad$ $i = C\dfrac{dv}{dt}$

$i = \dfrac{v}{R} = Gv$ $\qquad$ $i = \dfrac{1}{L}\displaystyle\int_{-\infty}^{t} v\, dt$ $\qquad$ $v = \dfrac{1}{C}\displaystyle\int_{-\infty}^{t} i\, dt$

Conductance

Figure: Circuit Elements

# Energy Storage in Linear Elements I

Energy is $w = \int v\ i\ dt$

**Inductance**

Where $v = L\frac{d\ i}{dt}$ and $i = 0$ at $t = 0$,

$$w_L = \int_0^T L\frac{d\ i}{dt}\ i\ dt = \int_0^I L\ i\ di = \frac{1}{2}L\ I^2 \qquad (16)$$

Inductance is a measure of the ability of a device to store energy in the form of moving charge or in the form of a magnetic field

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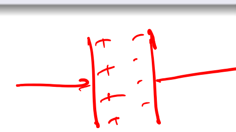
# Energy Storage in Linear Elements II

**Capacitance**

Where $i = C\frac{d\ v}{dt}$ and $v = 0$ at $t = 0$,

$$w_C = \int_0^T v\ C\frac{d\ v}{dt}\ dt = \int_0^V C\ v\ dv = \frac{1}{2}C\ V^2 \qquad (17)$$

Capacitance is a measure of the ability of a device to store energy in the form of separated charge or in the form of an electric field



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# Energy dissipation in Linear elements

**Resistance**

Where $v = R\ i$ and $i = 0$ at $t = 0$,

$i = V/R$

$$w_R = \int_0^T R\ i^2\ dt = \int_0^T \frac{v^2}{R} dt \tag{18}$$

When current is constant $i = I$

$$w_R = R\ I^2\ T = \frac{V^2}{R} T \tag{19}$$

Resistance is a measure of the ability of a device to dissipate power irreversibly





# Continuity of stored energy

$\frac{di}{dt}$: $i = 0$

$v = 0$

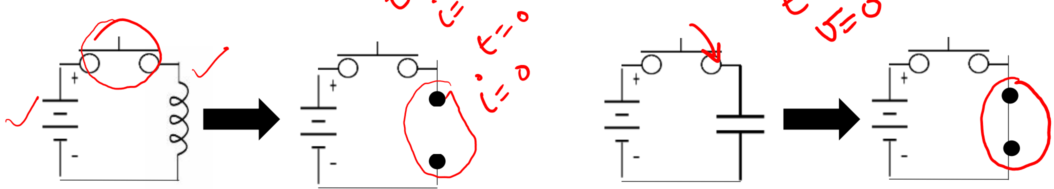
- The current in a inductance cannot change instantaneously
- The voltage across a capacitance cannot change instantaneously

$t = 0^-$ $i = 0$

$t = 0^+$ $i = 0$

$t = 0^-$ $V = 0$

$t = 0$ $V = 0$

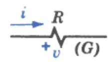
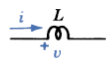
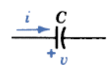
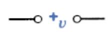
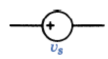
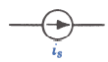


i(t)=V·(1−exp(−Rt/L))
at t=0, i=0 (open ckt)

V(t)=V(1−exp(−t/RC))
At t=0, V=0 (short ckt)

# Circuit Diagram Convention

$\frac{1}{R} = G$

| Element | Unit | Symbol | Characteristic |
|---|---|---|---|
| Resistance (Conductance) | ohm (siemen) |  | $v = Ri$ ($i = Gv$) |
| Inductance | henry |  | $v = L\frac{di}{dt}$ $\quad i = \frac{1}{L}\int_{-\infty}^{t} v\,dt$ |
| Capacitance | farad |  | $i = C\frac{dv}{dt}$ $\quad v = \frac{1}{C}\int_{-\infty}^{t} i\,dt$ |
| Short circuit | |  | $v = 0$ for any $i$ |
| Open circuit | |  | $i = 0$ for any $v$ |
| Voltage source | volt |  | $v = v_s$ for any $i$ |
| Current source | ampere |  | $i = i_s$ for any $v$ |

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