Chapter 1 : Quantities and Units in Electrical Circuit

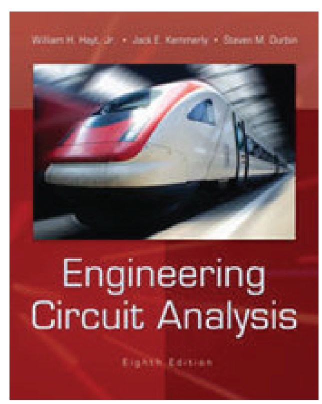
Course Objectives

After completed study this chapter, students will be able to :

- Learn how the electricity ; voltage and current happen.
- Understand all basic elements and units using in electrical and computer engineering.
- Introduce the basic components such as resistor , capacitor etc.
- Explain how to measure the electrical quantities using meter.
- Review the SI units.

Textbook

- William H. Hayt Jr., Jack E. Kemmerly and Steven M. Durbin "Engineering Circuit Analysis", 8th Edition, McGraw Hill 2013



Recommended book

[1] "Principles of Electric Circuits : Conventional Current" 9th edition Thomas L. Floyd , Prentice Hall 2010 : ISBN-13: 9780135073094

[2] "Introductory Circuit Analysis", 12nd edition by Robert L. Boylestad, Pearson 2010 : ISBN-13: 9780137146666

Prerequisites:

Pass physics course in freshman.

Course Evaluation:

1. Midterm exam	40 %
2. Final exam	40 %
3. Homeworks	10 %
4. Quizzes/Attendance	10 %

For those students who receive the total score below 60% will get a grade "F" and above 90% will be an "A". The other grades depend on an average of the class or using MUIC grading scale .

Instructors

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1.1 Brief History of Electricity

William Gilbert (1540–1603), English physician, founder of magnetic science, published *De Magnete*, a treatise on magnetism, in 1600.

Charles A. Coulomb (1736–1806), French engineer and physicist, published the laws of electrostatics in seven memoirs to the French Academy of Science between 1785 and 1791. His name is associated with the unit of charge.

James Watt (1736–1819), English inventor, developed the steam engine. His name is used to represent the unit of power.

Alessandro Volta (1745–1827), Italian physicist, discovered the electric pile. The unit of electric potential and the alternate name of this quantity (voltage) are named after him.

Hans Christian Oersted (1777–1851), Danish physicist, discovered the connection between electricity and magnetism in 1820. The unit of magnetic field strength is named after him.

André Marie Ampère (1775–1836), French mathematician, chemist, and physicist, experimentally quantified the relationship between electric current and the magnetic field. His works were summarized in a treatise published in 1827. The unit of electric current is named after him.

Georg Simon Ohm (1789–1854), German mathematician, investigated the relationship between voltage and current and quantified the phenomenon of resistance. His first results were published in 1827. His name is used to represent the unit of resistance.

Michael Faraday (1791–1867), English experimenter, demonstrated electromagnetic induction in 1831. His electric transformer and electromagnetic generator marked the beginning of the age of electric power. His name is associated with the unit of capacitance.

Joseph Henry (1797–1878), U.S. physicist, discovered self-induction around 1831, and his name has been designated to represent the unit of inductance. He had also recognized the essential structure of the telegraph, which was later perfected by Samuel F. B. Morse.

Carl Friedrich Gauss (1777–1855), German mathematician, and **Wilhelm Eduard Weber** (1804–1891), German physicist, published a treatise in 1833 describing the measurement of the earth's magnetic field. The gauss is a unit of magnetic field strength, while the weber is a unit of magnetic flux.

James Clerk Maxwell (1831–1879), Scottish physicist, discovered the electromagnetic theory of light and the laws of electrodynamics. The modern theory of electromagnetics is entirely founded upon Maxwell's equations.

Ernst Werner Siemens (1816–1892) and **Wilhelm Siemens** (1823–1883), German inventors and engineers, contributed to the invention and development of electric machines, as well as to perfecting electrical science. The modern unit of conductance is named after them.

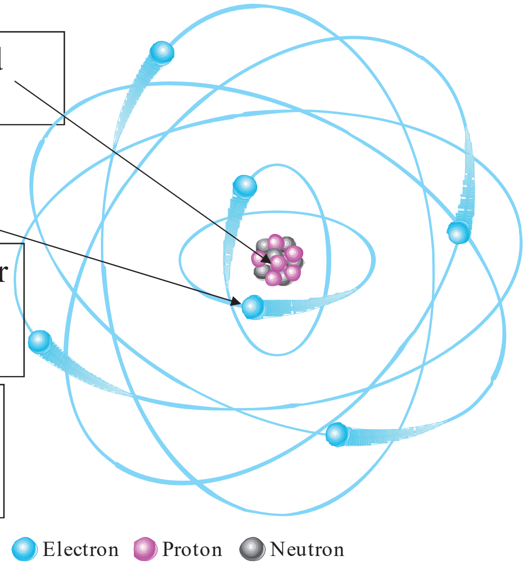
Heinrich Rudolph Hertz (1857–1894), German scientist and experimenter, discovered the nature of electromagnetic waves and published his findings in 1888. His name is associated with the unit of frequency.

Nikola Tesla (1856–1943), Croatian inventor, emigrated to the United States in 1884. He invented polyphase electric power systems and the induction motor and pioneered modern AC electric power systems. His name is used to represent the unit of magnetic flux density.

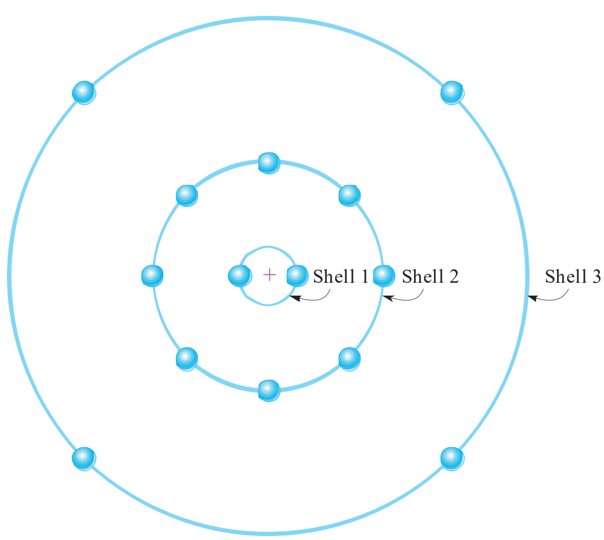
1.2 Charges Current and Voltage

The Bohr atom is a tool for visualizing atomic structure.

- The nucleus is positively charged and has the protons and neutrons.
- Electrons are negatively charged and in discrete shells.
- The atomic number is the number of protons and determines the particular element.
- In the neutral atom, the number of electrons is equal to the number of protons.



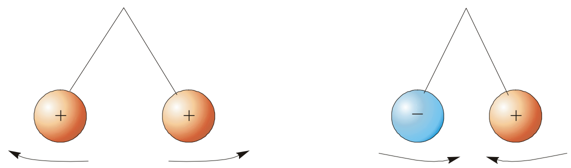
The outer shell is called the *valence shell*. Electrons in this shell are involved in chemical reactions and in metals they account for electrical and thermal conductivity.



Charges

There is a force (F) between charges. Like charges repel ; unlike charges attract.

- The force is directly proportional to charge.
- The force is inversely proportional to square of distance (for point sources).



- 1 electron has a charge = - 1.6 x 10^{-19} coulomb
- 1 coulomb consists of 6.28 x 10^{18} electrons.

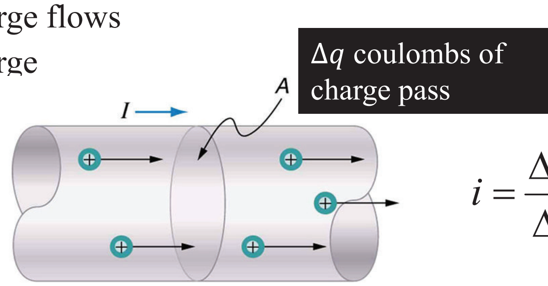
Current

Electrical current is the time rate of flow of electrical charge through a conductor or circuit element. The units are amperes (A), which are equivalent to coulombs per second (C/s).

- Current exists whenever charge flows
- Current: the flow rate of charge

$$i(t) = \frac{dq(t)}{dt}$$

$$q(t) = \int_{t_0}^{t} i(t)dt + q(t_0)$$

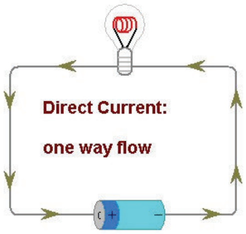


$$i = \frac{\Delta q}{\Delta t}$$

ONE AMPERE OF CURRENT CARRIES ONE COULOMB OF CHARGE EVERY SECOND. 1 A = 1COULOMB PER SEC.

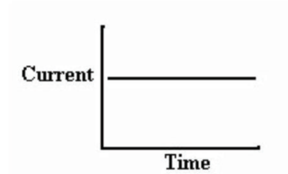
We define the direction of positive charge flow as positive current direction.

There are 2 types of Current



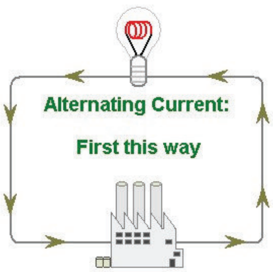
DC = Direct Current - current flows in one direction

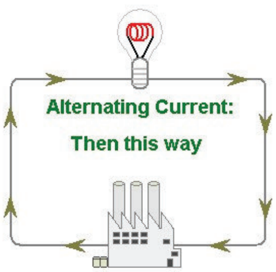
Example: Battery

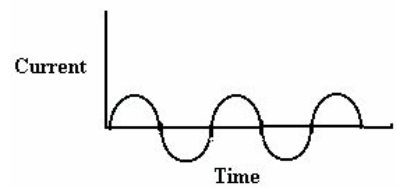


AC = Alternating Current- current reverses direction many times per second. This suggests that AC devices turn OFF and ON.

Example: Wall outlet (progress energy)







Energy

The flow of charge is established by an external "pressure" derived from the energy that a mass has by virtue of its position: **Potential energy.**

Energy: the capacity to do work

If a mass (m) is raised to some height (h) above a reference plane, it has a measure of potential energy expressed in joules (J) that is determined by

W (potential energy) = *mgh*

where g is the gravitational acceleration (9.8 m/s^2)

Voltage

A potential difference of 1 volt (V) exists between two points if 1 joule (J) of energy is exchanged in moving 1 coulomb (C) of charge between the two points . The unit of measurement **volt** was chosen to honor Alessandro Volta

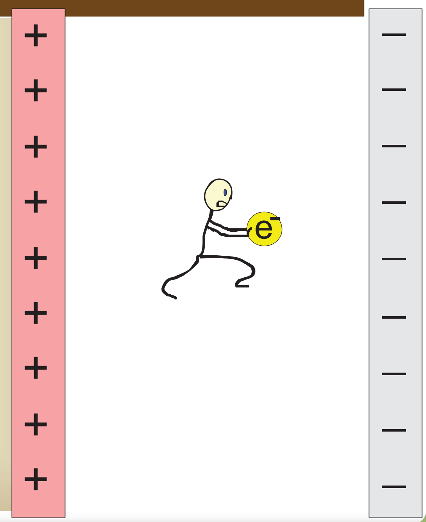
Potential difference between two points is determined by: **V = W/Q**

Voltage (V) is the energy (W) per charge (Q); it is responsible for establishing current.

$$V = \frac{W}{Q}$$

Work is done as a charge is moved in the electric field from one potential to another.

Voltage is the work per charge done against the electric field.

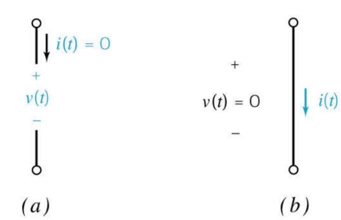


Definition of voltage

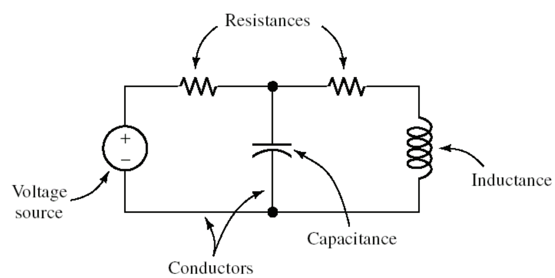
One volt is the potential difference (voltage) between two points when one joule of energy is used to move one coulomb of charge from one point to the other.

$$V = \frac{W}{Q}$$

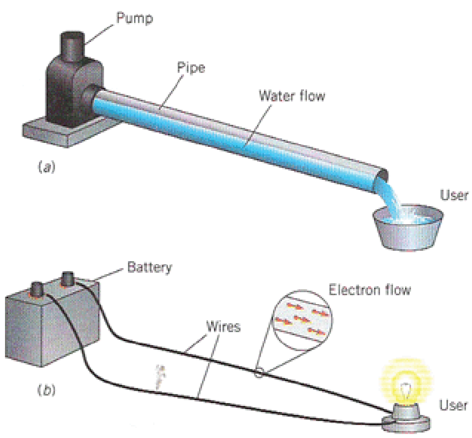
An *electric circuit* consists of various types of elements connected by connectors. (Note: "*open*" or "*short*" circuit)



open *short*



Electricity can be symbolic of Fluids



A pump basically works on TWO IMPORTANT PRINCIPLES concerning its flow

- There is a **PRESSURE DIFFERENCE** where the flow begins and ends
- A certain **AMOUNT** of flow passes each **SECOND**.

A circuit basically works on TWO IMPORTANT PRINCIPLES

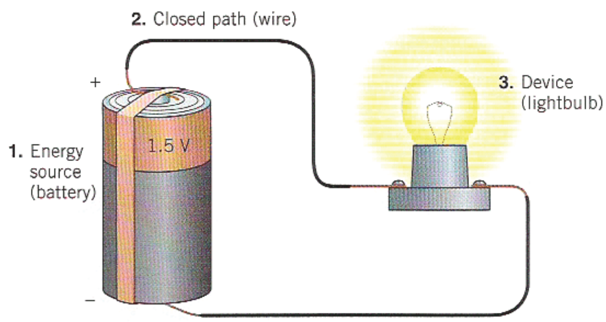
- There is a "**POTENTIAL DIFFERENCE aka VOLTAGE**" from where the charge begins to where it ends
- The **AMOUNT of CHARGE** that flows **PER SECOND** is called **CURRENT.**

1.3 Circuit Elements

All electric circuits have three main parts

1. A source of energy
2. A closed path
3. A device which uses the energy

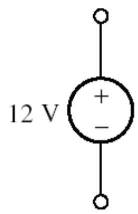
If ANY part of the circuit is open the device will not work!



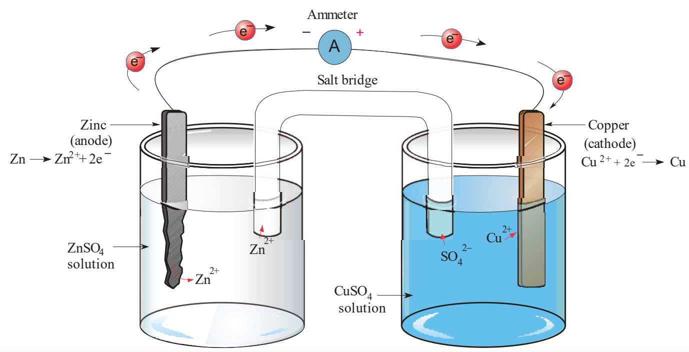
1.3.1 Voltage Sources

Independent Voltage Sources : maintain a specific voltage across its terminals, independent of other elements in the circuit.

- Batteries (chemical action)
- Generators (electromechanical)
- Power supplies (rectification)

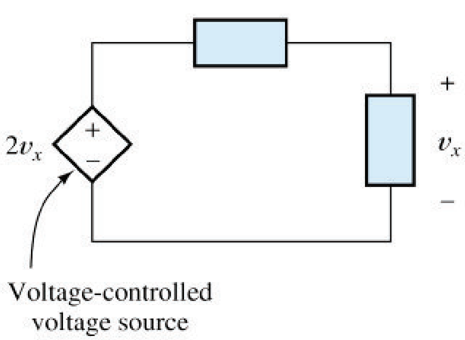


(a) Constant or
dc voltage source



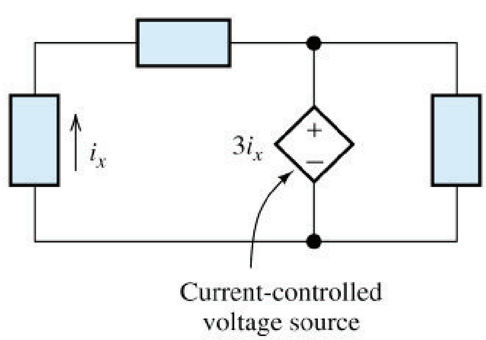
Dependent (or Controlled) Voltage Sources

voltage-controlled voltage source (VCVS)



The voltage source is controlled by the voltage drop across some elements in the circuit

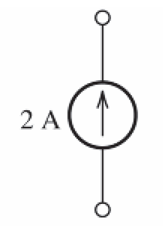
current-controlled voltage source (CCVS)



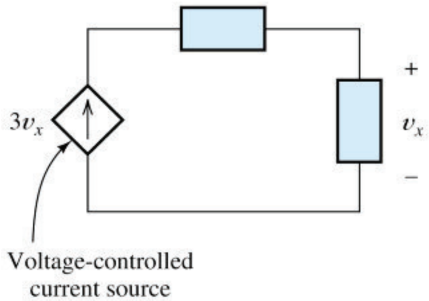
The voltage source is controlled by the current passing some elements in the circuit

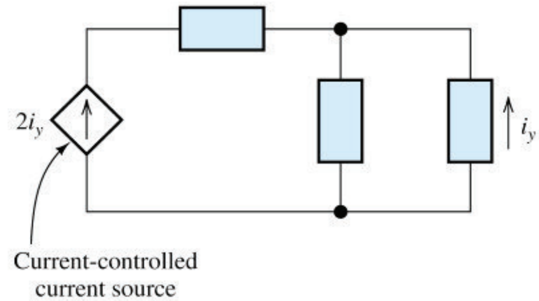
1.3.2 Current Sources

Independent Current Source : forces a specific current to flow through itself, independent of other elements in the circuit.



Dependent (or Controlled) Current Sources



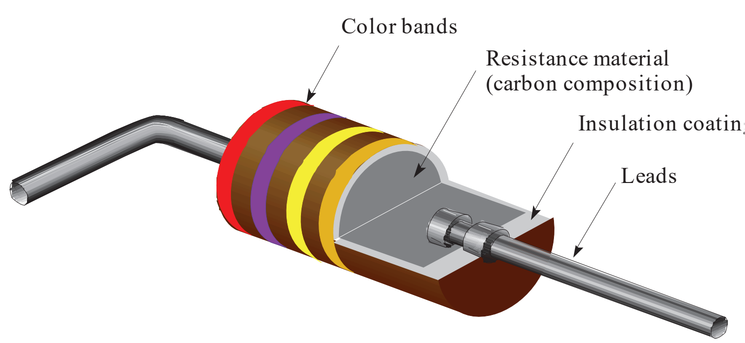


The current source is controlled by the voltage drop across some elements in the circuit (VCCS).

The current source is controlled by the current passing some elements in the circuit (CCCS).

1.3.3 Resistor

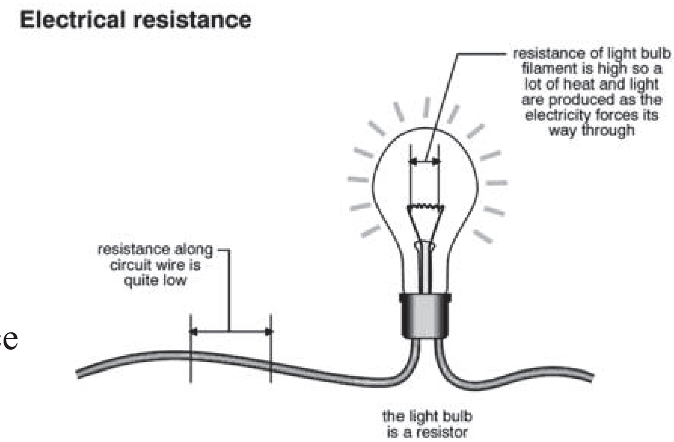
Resistance (R) – is defined as the restriction of electron flow. It is due to interactions that occur at the atomic scale. For example, as electron move through a conductor they are attracted to the protons on the nucleus of the conductor itself. This attraction doesn't stop the electrons, just slow them down a bit and cause the system to waste energy.



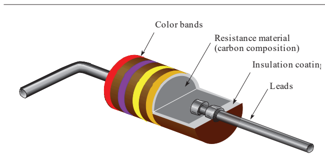
One ohm (1 Ω) is the resistance if one ampere (1 A) is in a material when one volt (1 V) is applied.

Conductance is the reciprocal of resistance. $G = \dfrac{1}{R}$

Components designed to have a specific amount of resistance are called *resistors*.



The unit for resistance is the OHM, Ω



Resistance value, first three bands:

First band– 1st digit
Second band– 2nd digit
*Third band– multiplier (number of zeros following the 2nd digit)

Color	Digit	Multiplier	Tolerance
Black	0	10^0	
Brown	1	10^1	1% (five band)
Red	2	10^2	2% (five band)
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	

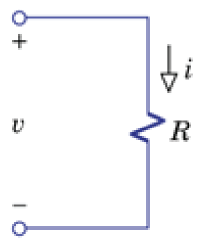
Fourth band– tolerance

Color	Digit	Multiplier	Tolerance
Gold	±5%	10^{-1}	5% (four band)
Silver	±10%	10^{-2}	10% (four band)
No band	±20%		

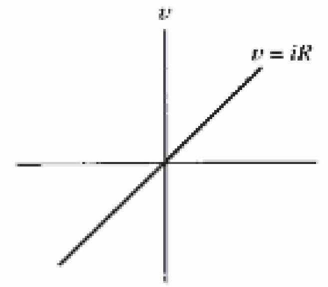
* For resistance values less than 10Ω, the third band is either gold or silver. Gold is for a multiplier of 0.1 and silver is fo a multiplier of 0.01.

1.4 Ohm's Law and Electrical Power

- Ohm's Law: The voltage and current are directly proportional to each other.

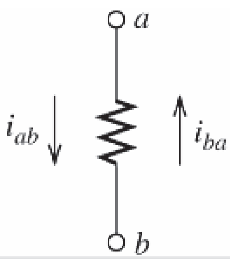


$$i = \frac{v}{R}$$

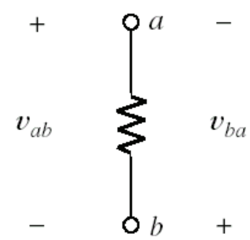


(a) Resistance symbol (b) Ohm's law

When using Ohm's Law, reference current should flow from "+" to "-"



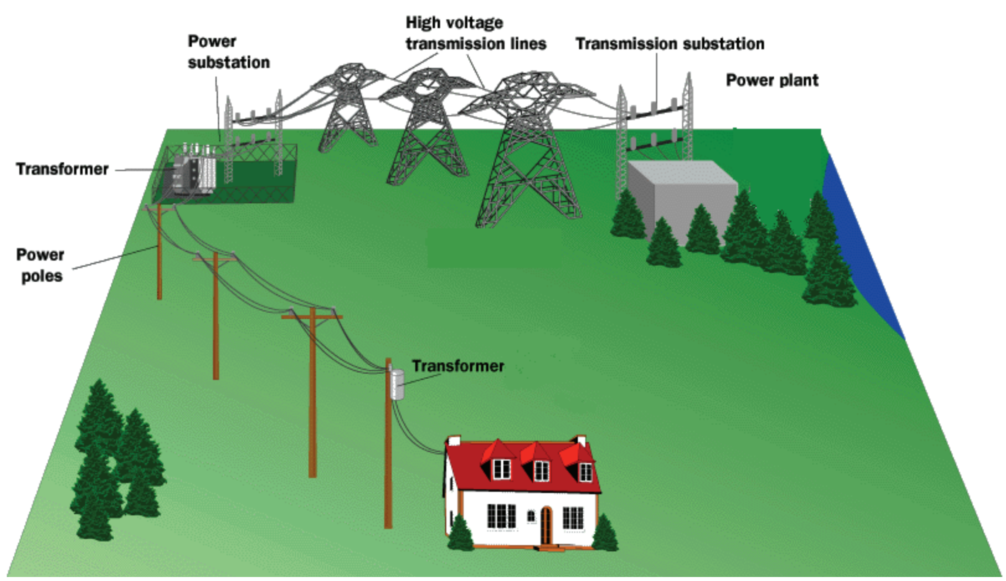
$$i_{ab} = -i_{ba}$$



$$v_{ab} = -v_{ba}$$

Electrical POWER

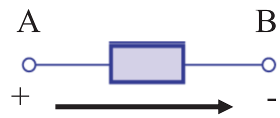
POWER is the rate at which work (energy) is done. $p = \frac{\Delta w}{\Delta t}$



- ***Consumed*** Power: The rate of losing energy for charge or the rate of consuming by elements

$$p = \frac{\Delta w}{\Delta t}$$

$$v \cdot i = \frac{\Delta w}{\Delta q} \cdot \frac{\Delta q}{\Delta t} = p$$



By using Ohm's Law :

$$\boldsymbol{p = vi = i^2 R = v^2/R}$$

$$v = \frac{\Delta w}{\Delta q} \qquad i = \frac{\Delta q}{\Delta t}$$

For using the formulation, reference current should flow from "+" to "-" (Passive polarity convention)

1.5 International System of units : SI

SI base units

The SI is founded on seven *SI base units* for seven *base quantities* assumed to be mutually independent, as given in Table 1.

Table 1. SI base units

	SI base unit	
Base quantity	**Name**	**Symbol**
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

The 20 SI prefixes used to form decimal multiples and submultiples of SI units are given in Table 5.

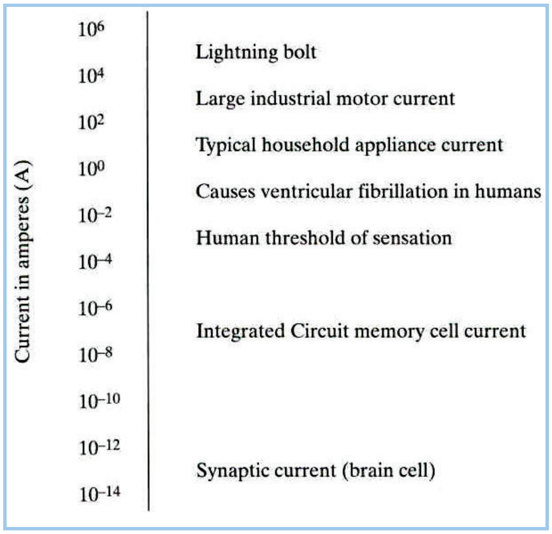
Table 5. SI prefixes

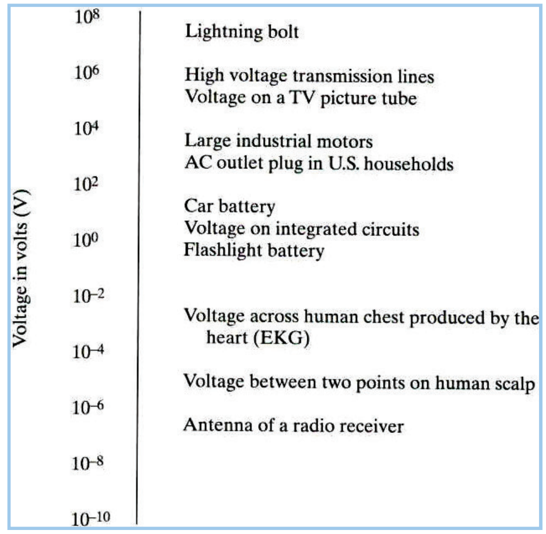
Factor	Name	Symbol	Factor	Name	Symbol
10^{24}	yotta	Y	10^{-1}	deci	d
10^{21}	zetta	Z	10^{-2}	centi	c
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	µ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atto	a
10^{2}	hecto	h	10^{-21}	zepto	z
10^{1}	deka	da	10^{-24}	yocto	y

SI DERIVED BASIC ELECTRICAL UNITS

power, radiant flux	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
electric charge, quantity of electricity	coulomb	C	-	$s \cdot A$
electric potential difference, electromotive force	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
electric conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
magnetic flux	weber	Wb	V·s	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$

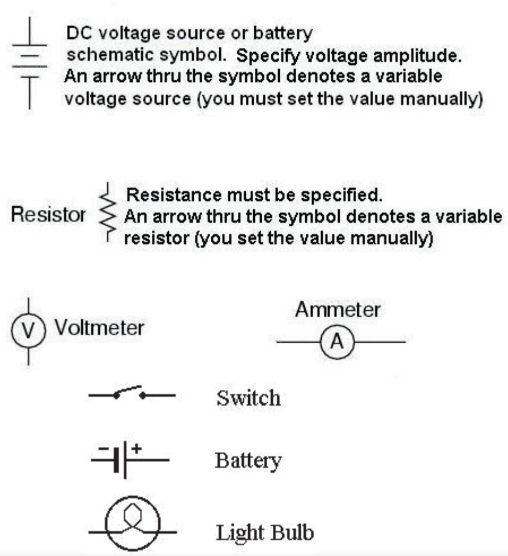
CURRENT AND VOLTAGE RANGES





1.6 Voltmeter and Ammeter

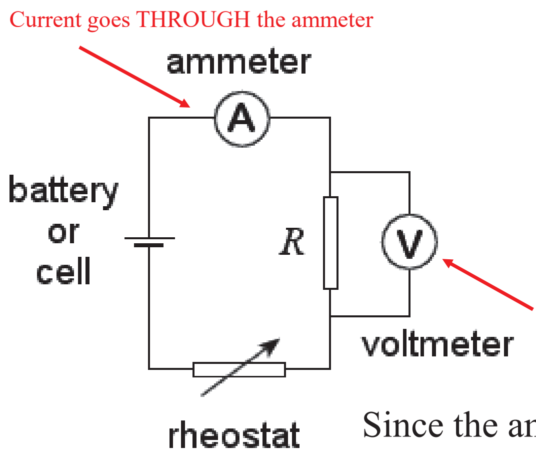
Before you begin to understand circuits you need to be able to draw what they look like using a set of standard symbols understood anywhere in the world.



For the battery symbol, the LONG line is considered to be the POSITIVE terminal and the SHORT line , NEGATIVE.

The VOLTMETER and AMMETER are special devices you place IN or AROUND the circuit to measure the VOLTAGE and CURRENT.

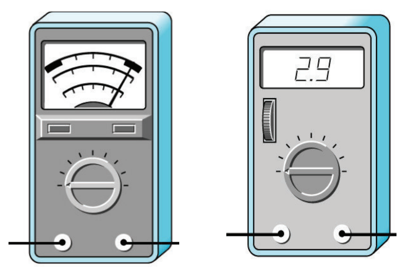
The voltmeter and ammeter cannot be just placed anywhere in the circuit. They must be used according to their



Since a voltmeter measures voltage or POTENTIAL DIFFERENCE it must be placed **ACROSS** the device you want to measure. That way you can measure the

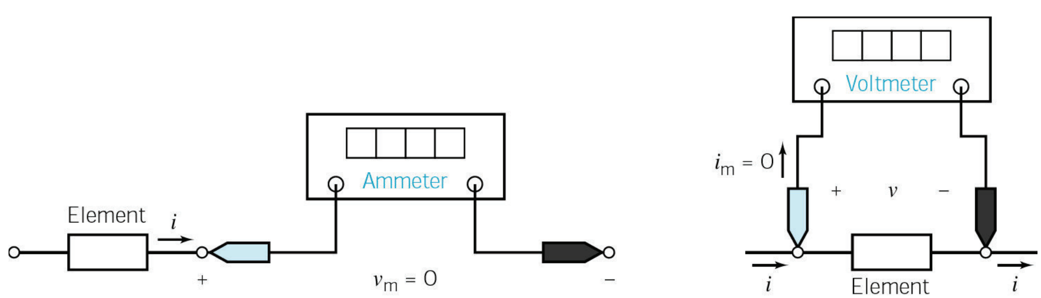
Voltmeter is drawn ACROSS the resistor

Since the ammeter measures the current or FLOW it must be placed in such a way as the charges go **THROUGH** the device.



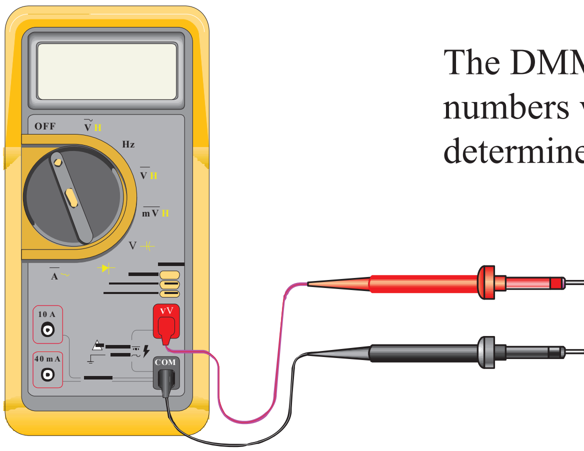
(a) (b)

(a) An ideal ammeter measures the current flow through its terminals and has zero voltage.
(b) An ideal voltmeter measures the voltage across its terminals and has zero terminal current.



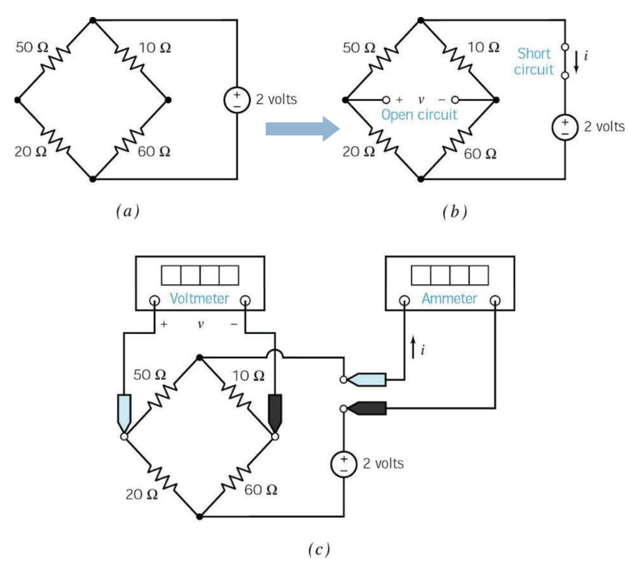
(a) (b)

An important multipurpose instrument is the DMM, which can measure voltage, current, and resistance. Many include other measurement options.



The DMM provides a display of numbers with decimal point accuracy determined by the chosen scale.

Ideal voltmeters (ammeters) act like open (short) circuits.

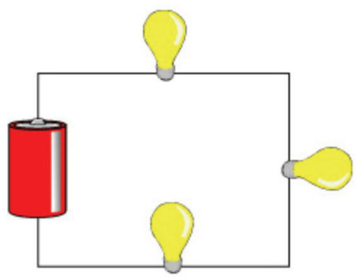


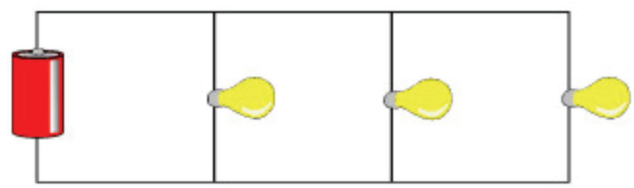
(*a*) An example circuit, (*b*) plus an open circuit and a short circuit. (c) The open circuit is replaced by a voltmeter, and the short circuit is replaced by an ammeter. All resistances are in ohms.

1.7 Series and Parallel Circuits

There are 2 basic ways to wire a circuit. Keep in mind that a resistor could be ANYTHING (bulb, toaster, ceramic material…etc)

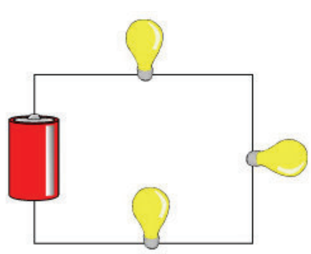
Series – One after another
Parallel – between a set of junctions and parallel to each other





Series Circuit

In in series circuit, the resistors are wired one after another. Since they are all part of the SAME LOOP they each experience the SAME AMOUNT of current. In figure, however, you see that they all exist BETWEEN the terminals of the battery, meaning they SHARE the potential (voltage).



$$I_{(series)Total} = I_1 = I_2 = I_3$$
$$V_{(series)Total} = V_1 + V_2 + V_3$$

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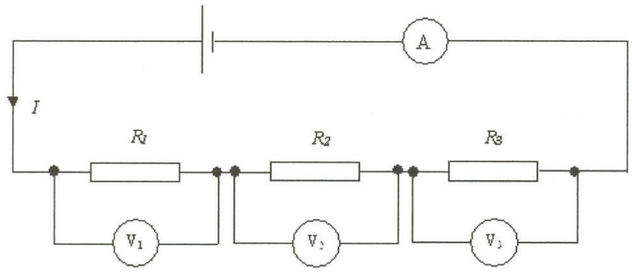
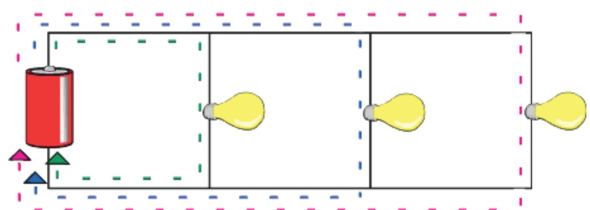


As the current goes through the circuit, the charges must USE ENERGY to get through the resistor. So each individual resistor will get its own individual potential voltage). We call this VOLTAGE DROP.

$$V_{(series)Total} = V_1 + V_2 + V_3; \quad \Delta V = IR$$
$$(I_T R_T)_{series} = I_1 R_1 + I_2 R_2 + I_3 R_3$$
$$R_{series} = R_1 + R_2 + R_3$$
$$R_s = \sum R_i$$

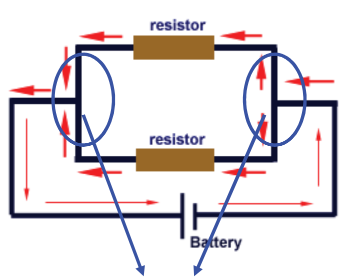
Note: They may use the terms "effective" or "equivalent" to mean TOTAL!

Parallel Circuit



In a parallel circuit, we have multiple loops. So the current splits up among the loops with the individual loop currents **adding** to the total current

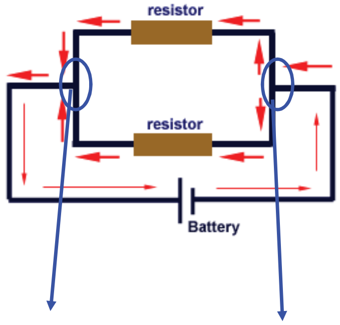
It is important to understand that parallel circuits will all have some position where the current splits and comes back together. We call these **JUNCTIONS**. The current going IN to a junction will always equal the current going OUT of a junction.



$$I_{(parallel)Total} = I_1 + I_2 + I_3$$

Regarding Junctions :

$$I_{IN} = I_{OUT}$$



Notice that the JUNCTIONS both touch the POSTIVE and NEGATIVE terminals of the battery. That means you have the SAME potential difference down EACH individual branch of the parallel circuit. This means that the individual voltages drops are equal.

This junction touches the **POSITIVE** terminal

This junction touches the **NEGATIVE** terminal

$$V_{(parallel)Total} = V_1 = V_2 = V_3$$

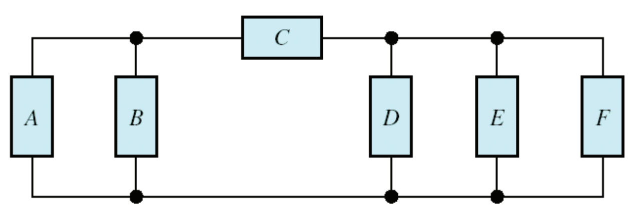
$$I_{(parallel)Total} = I_1 + I_2 + I_3; \ \Delta V = IR$$

$$\left(\frac{V_T}{R_T}\right)_{Parallel} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}$$

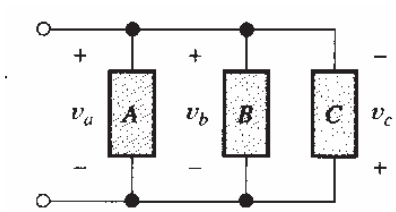
$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

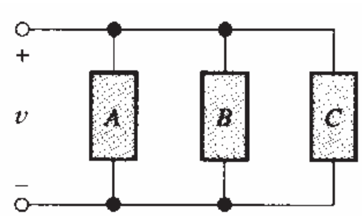
$$\frac{1}{R_P} = \sum \frac{1}{R_i}$$

Two or more circuit elements are *in parallel* if both ends of one element are connected *directly* to corresponding ends of others. In the following figure, D,E,F are in parallel, but not B,D.



The voltage across parallel elements are equal in magnitude and have the same polarity.



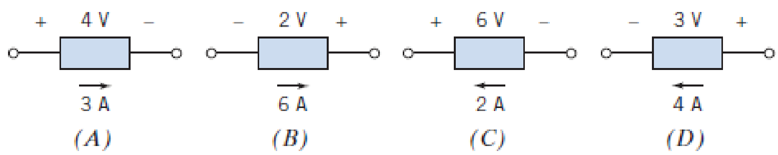


Self-Test

1. Convert the following to engineering notation :

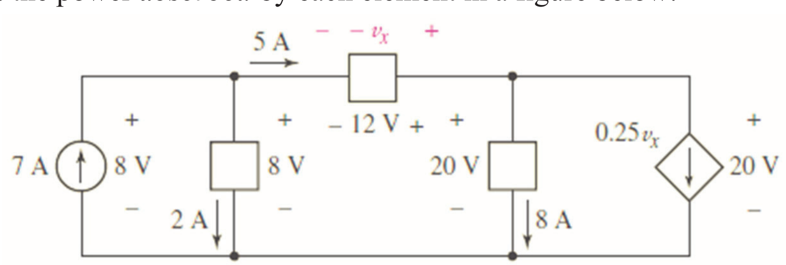
a) 0.045 W	(Ans 45 mW)	d) 200000 Hz	(Ans 200 KHz)
b) 0.000015 A	(Ans 15 µA)	e) 5600 Ω	(Ans 5.6 KΩ)
c) 2200 pF	(Ans 2.2 nF)	f) 20 x 10^{-3} V	(Ans 20 mV)

2. There are four circuit elements shown in the figure below :



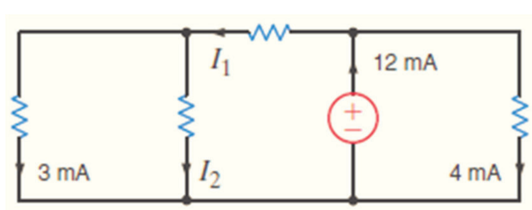
-Which of the devices supply 12 W. [Ans (B) and (C)]
-Which of the devices absorb 12 W. [Ans (A) and (D)]
-What is the value of the power received by device (B) [Ans - 12 W]
-What is the value of the power dilivered by device (B) [Ans + 12 W]
-What is the value of the power dilivered by device (D) [Ans - 12 W]

3. Find the power *absorbed* by each element in a figure below:



(Ans : (left to right) -56 W; 16 W ; -60 W; 160 W; -60 W)

4. Find the current I_1 and I_2 in a figure below:



(Ans I_1 = 8 mA , I_2 = 5 mA)