This material will be posted on the course web site.

Sirindhorn International Institute of Technology

Thammasat University

School of Information, Computer and Communication Technology

Lecture Notes:
ECS 303 Basic Electrical Engineering
Semester 1/2009
Part 1

Dr.Prapun Suksompong[1]

October 29, 2009

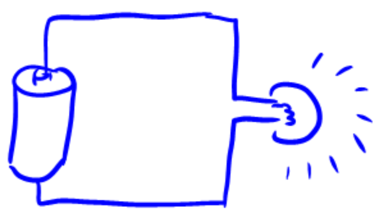
[1]Speical thanks to Dr.Waree Kongprawechnon and Dr.Somsak Kittipiyakul for earlier versions of the notes. Parts of the notes were compiled from C.K. Alexander and M.N.O. Sadiku, *Fundamentals of Electric Circuits*, 4th ed., McGraw-Hill, International Edition, 2009 and G. Rizzoni, *Principles and Applications of Electrical Engineering*, 5th ed., Mc-Graw-Hill, International Edition, 2007

CHAPTER 1

Basic Concepts

In electrical engineering, we are often interested in communicating or transferring energy from one point to another. To do this requires an interconnection of electrical devices. Such interconnection is referred to as an **electric circuit**, and each component of the circuit is known as an **element**.

- An **electric circuit** is an interconnection of electrical elements.



1.1. Systems of Units

As engineers, we deal with measurable quantities. Our measurement must be communicated in standard language that virtually all professionals can understand irrespective of the country. Such an international measurement language is the International System of Units (SI).

In this system, there are six principal units from which the units of all other physical quantities can be derived.

Quantity	Basic Unit	Symbol
Length	meter	m
Mass	kilogram	Kg
Time	second	s
Electric Current	ampere	A
Temperature	kelvin	K
Luminous Intensity	candela	cd
Charge	coulomb	C

One great advantage of SI unit is that it uses prefixes based on the power of 10 to relate larger and smaller units to the basic unit.

Multiplier	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Ex.(change of units)

1.2. Circuit Variables

Charge: The concept of electric charge is the underlying principle for all electrical phenomena. Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs (C). The charge of an electron is -1.602×10^{-19} C.

- The coulomb is a large unit for charges. In 1 C of charge, there are $1/(1.602 \times 10^{-19}) = 6.24 \times 10^{18}$ electrons. Thus realistic or laboratory values of charges are on the order of pC, nC, or μC.
- A large power supply capacitor can store up to 0.5 C of charge.

Law of Conservation of Charge: Charge can neither be created nor destroyed, only transferred.

Current: The time rate of change of charge, measured in amperes (A). Mathematically,

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

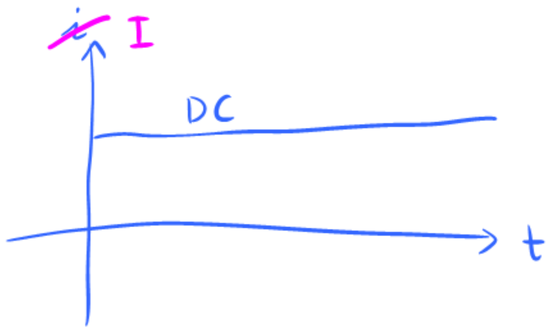
Note:

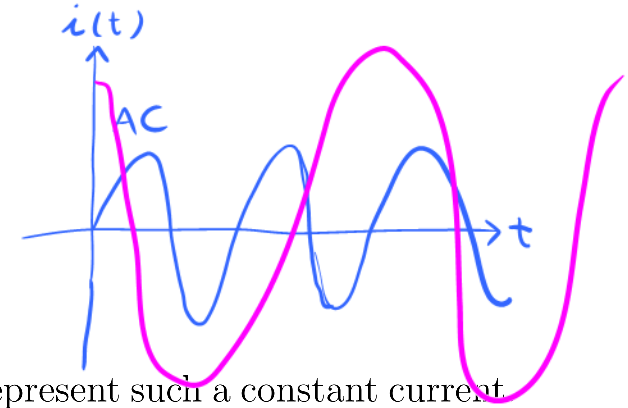
- 1 ampere (A) = 1 coulomb/second (C/s).
- The charge transferred between time t_1 and t_2 is obtained by

$$q = \int_{t_1}^{t_2} i dt$$

Two types of currents:
1) A **direct current** (DC) is a current that remains constant with time.
2) An **alternating current** (AC) is a current that varies with time.

- Such AC current is used in your household, to run the air conditioner, refrigerator, washing machine, and other electric appliances.





By convention the symbol I is used to represent such a constant current. A time-varying current is represented by the symbol i.

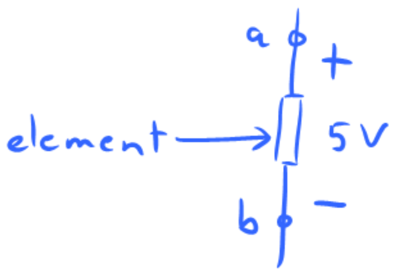
Voltage (or potential difference): the energy required to move a unit charge though an element, measured in volts (V). The voltage between two points a and b in a circuit is denoted by v_{ab} and can be interpreted in 2 ways:
1) point a is at a potential of v_{ab} volts higher than point b, or
2) the potential at point a with respect to point b is v_{ab}.

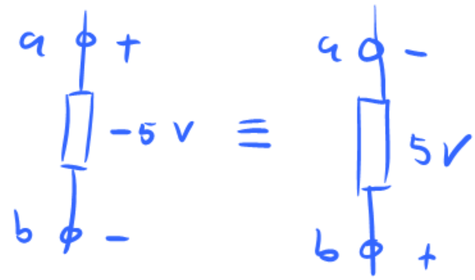
Note:

- 1 volt (V) = 1 joule/coulomb = 1 newton-meter/coulomb
- $v_{ab} = -v_{ba}$
- Mathematically,

$$v_{ab} = \frac{dw}{dq}$$

where w is the energy in joules (J) and q is charge in coulombs (C).





The plus (+) and minus (-) signs at the points a and b are used to define reference direction or voltage polarity.

Like electric current, a constant voltage is called a **DC voltage** and is represented by V, whereas a sinusoidally time-varying voltage is called an **AC voltage** and is represented by v. A dc voltage is commonly produced by a battery; ac voltage is produced by an electric generator.

Current and voltage are the two basic variables in electric circuits. The common term signal is used for an electric quantity such as a current or a voltage (or even electromagnetic wave) when it is used for conveying information. Engineers prefer to call such variables signals rather than mathematical functions of time because of their importance in communications and other disciplines.

For practical purposes, we need to be able to find/calculate/measure more than the current and voltage. We all know from experience that a 100-watt bulb gives more light than a 60-watt bulb. We also know that when we pay our bills to the electric utility companies, we are paying for the electric energy consumed over a certain period of time. Thus power and energy calculations are important in circuit analysis.

Power: time rate of *expending* or *absorbing* energy, measured in watts (W). Mathematically, the instantaneous power

$$p = \frac{dw}{dt} = \frac{dw}{dq}\frac{dq}{dt} = vi$$

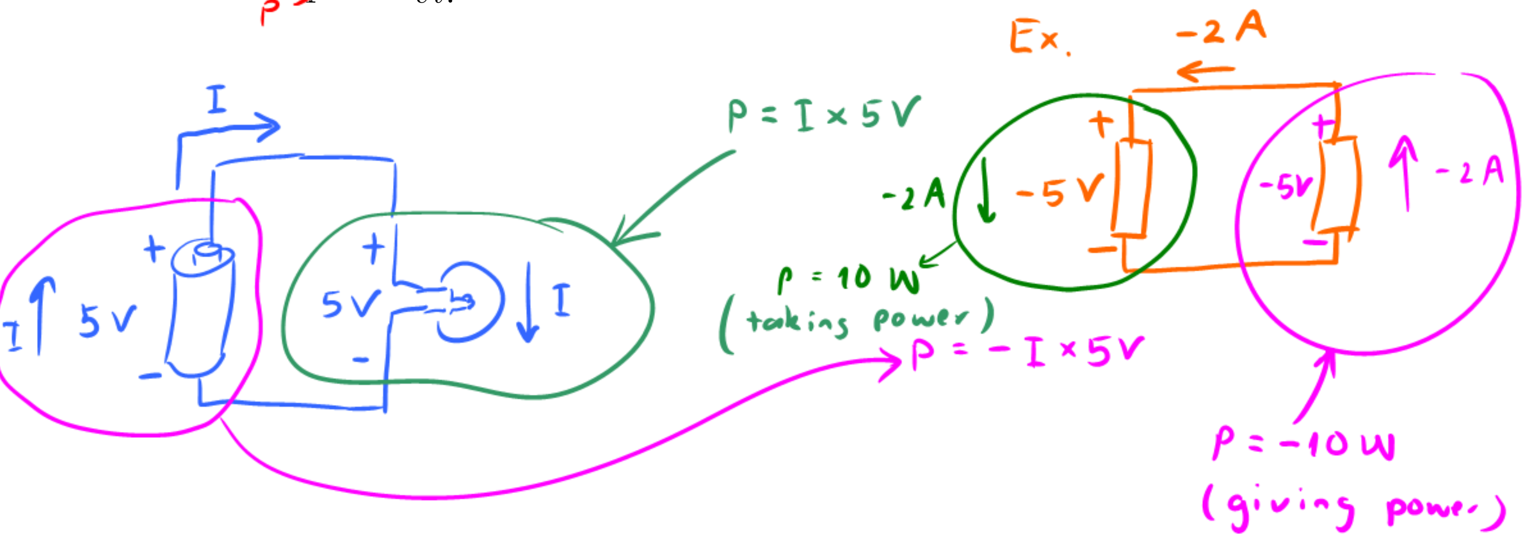
Sign of power

- **Plus sign**: Power is absorbed by the element. (resistor, inductor)

- **Minus sign**: Power is supplied by the element. (battery, generator)

Passive sign convention:

- If the current enters through the positive polarity of the voltage, $P = vi$.
- If the current enters through the negative polarity of the voltage, $P = -vi$.



Law of Conservation of Energy: Energy can neither be created nor destroyed, only transferred.

- For this reason, the algebraic sum of power in a circuit, at any instant of time, must be zero.
- The total power supplied to the circuit must balance the total power absorbed.

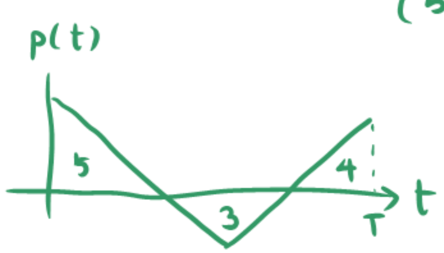
Energy: the energy absorbed or supplied by an element from time 0 to t is

$$w = \int_0^t p\, dt = \int_0^t vi\, dt.$$

[J] (joules)

The electric power utility companies measure energy in watt-hours (Wh), where 1 Wh = 3600 J.

area under the curve (be careful with "negative area")



Energy from time 0 to T

$\int_0^T p(t)\,dt = 5 + (-3) + 4 = 6$ J

1.3. Circuit Elements

There are 2 types of elements found in electrical circuits.

1) **Active elements** (is capable of generating energy), e.g., generators, batteries, and operational amplifiers (Op-amp).

2) **Passive element**, e.g., resistors, capacitors and inductors.

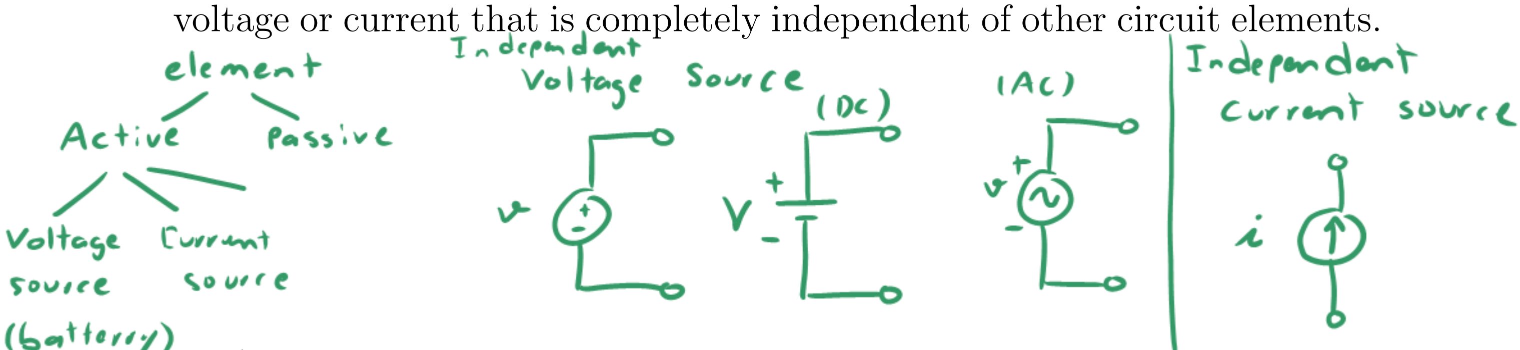
The most important active elements are voltage and current sources:

(a) **Voltage source** provides the circuit with a specified voltage (e.g. a 1.5V battery)

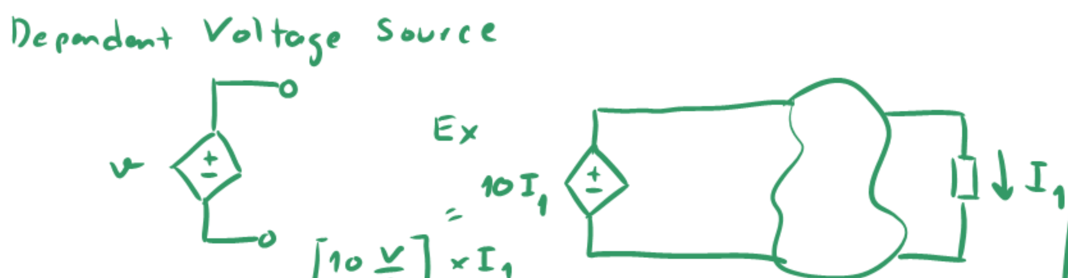
(b) **Current source** provides the circuit with a specified current (e.g. a 1A current source).

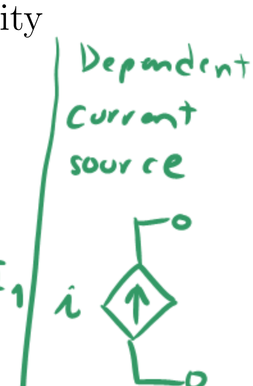
In addition, we may characterize the voltage or current sources as:

1) **Independent source**: An active element that provides a specified voltage or current that is completely independent of other circuit elements.



2) **Dependent source**: An active element in which the source quantity is controlled by another voltage or current.



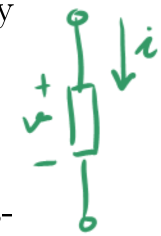


The key idea to keep in mind is that a voltage source comes with polarities (+ -) in its symbol, while a current source comes with an arrow, irrespective of what it depends on.

CHAPTER 2

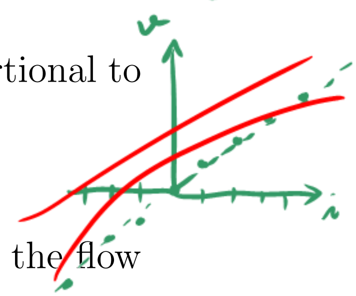
Basic Laws

Here we explore two fundamental laws that govern electric circuits (Ohm's law and Kirchhoff's laws) and discuss some techniques commonly applied in circuit design and analysis.



2.1. Ohm's Law

Ohm's law shows a relationship between voltage and current of a resistive element such as conducting wire or light bulb.



Ohm's Law: The voltage v across a resistor is directly proportional to the current i flowing through the resistor.

$$v = iR,$$

where R = resistance of the resistor, denoting its ability to resist the flow of electric current. The resistance is measured in ohms (Ω).

- To apply Ohm's law, the direction of current i and the polarity of voltage v must conform with the passive sign convention. This implies that current flows from a higher potential to a lower potential in order for $v = iR$. If current flows from a lower potential to a higher potential, $v = -iR$.

The resistance R of a cylindrical conductor of cross-sectional area A, length L, and conductivity σ is given by

$$R = \frac{L}{\sigma A}.$$

Alternatively,

$$R = \rho \frac{L}{A}$$

where ρ is known as the resistivity of the material in ohm-meters. Good conductors, such as copper and aluminum, have low resistivities, while insulators, such as mica and paper, have high resistivities.

Remarks:

(a) $R = v/i$

(b) Conductance :

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

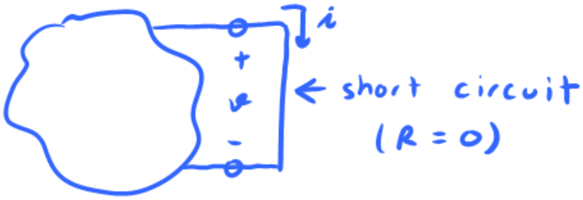
The unit of G is the mho[1] (℧) or siemens[2] (S)

(c) The two extreme possible values of R.

(i) When $R = 0$, we have a **short circuit** and

$$v = iR = 0$$

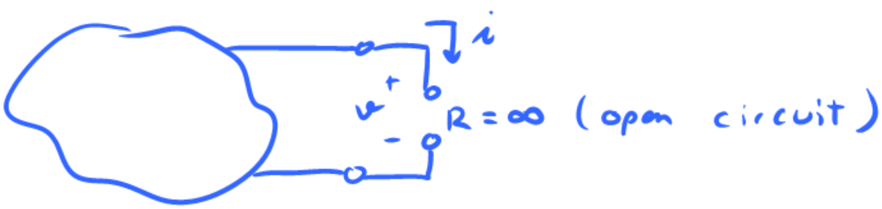
showing that $v = 0$ for any i.



(ii) When $R = \infty$, we have an **open circuit** and

$$i = \lim_{R \to \infty} \frac{v}{R} = 0$$

indicating that $i = 0$ for any v.



Remarks:

- A resistor is either fixed or variable. Most resistors are of the fixed type, meaning their resistance remains constant.
- A common variable resistor is known as a **potentiometer** or **pot** for short
- Not all resistors obey Ohms law. A resistor that obeys Ohms law is known as a linear resistor.
  - A nonlinear resistor does not obey Ohms law.
  - Examples of devices with nonlinear resistance are the lightbulb and the diode.
  - Although all practical resistors may exhibit nonlinear behavior under certain conditions, we will assume in this class that all elements actually designated as resistors are linear.

[1] Yes, this is NOT a typo! It was derived from spelling ohm backwards.

[2] In English, the term siemens is used both for the singular and plural.

Using Ohm's law, the power p dissipated by a resistor R is

$$p = vi = i^2 R = \frac{v^2}{R}.$$

Ex. $R = 12\,\Omega$, $V = 110\,V$ $\Rightarrow I = ?$ $9.167\,A$ $= \frac{V}{R}$

The **power rating** is the maximum allowable power dissipation in the resistor. Exceeding this power rating leads to overhearing and can cause the resistor to burn up.

Ex. Determine the minimum resistor size that can be connected to a 1.5V battery without exceeding the resistor's $\frac{1}{4}$-W power rating.

$p = \frac{v^2}{R}$

$\frac{1}{4} = \frac{(1.5)^2}{R}$

$R = (1.5)^2 \times 4 = \frac{3}{2} \times \frac{3}{2} \times 4 = \boxed{9}$

$\frac{v^2}{R} \le \frac{1}{4}$

$9 = 4v^2 \le R$

2.2. Node, Branches and Loops

Since the elements of an electric circuit can be interconnected in several ways, we need to understand some basic concept of network topology.

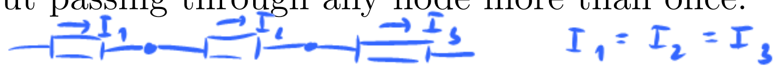
- Network = interconnection of elements or devices
- Circuit = a network with closed paths

Branch: A branch represents a single element such as a voltage source or a resistor. A branch represents any two-terminal element.

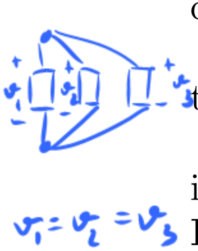
Node: A node is the point of connection between two or more branches. It is usually indicated by a dot in a circuit.

- If a short circuit (a connecting wire) connects two nodes, the two nodes constitute a single node.

Loop: A loop is any closed path in a circuit. A closed path is formed by starting at a node, passing through a set of nodes and returning to the starting node without passing through any node more than once.



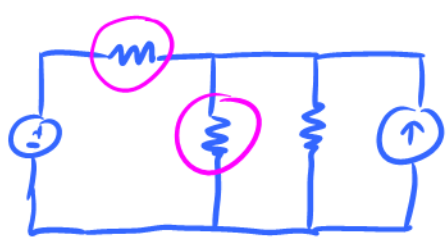
Series: Two or more elements are in **series** if they are cascaded or connected sequentially and consequently carry the *same current*.



Parallel: Two or more elements are in **parallel** if they are connected to the same two nodes and consequently have the *same voltage* across them.

Elements may be connected in a way that they are neither in series nor in parallel.

Ex.



Remarks: A loop is said to be **independent** if it contains a branch which is not in any other loop. Independent loops or paths result in independent sets of equations. A network with b branches, n nodes, and ℓ independent loops will satisfy the fundamental theorem of network topology:

$$b = \ell + n - 1.$$

2.3. Kirchhoff's Laws

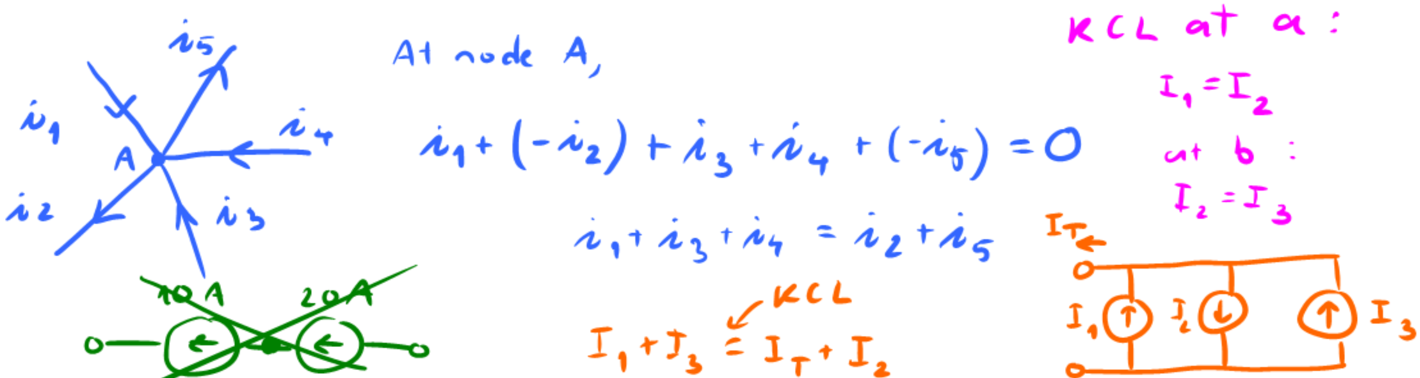
Ohms law coupled with Kirchhoffs two laws gives a sufficient, powerful set of tools for analyzing a large variety of electric circuits.

Kirchhoff's current law (KCL): the *algebraic sum* of current entering a node (or a closed boundary) is zero. Mathematically,

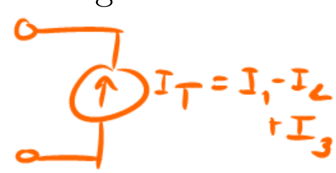
$$\sum_{n=1}^{N} i_n = 0$$

KCL is based on **the law of conservation of charge**. An alternative form of KCL is

Sum of currents (or charges) entering a node
= Sum of the currents (charges) leaving the node.



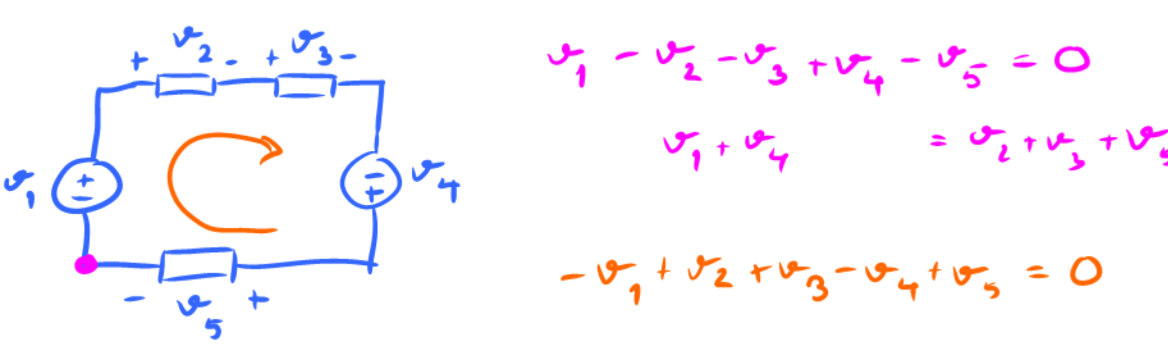
A Kirchhoff's voltage law (KVL): the algebraic sum of all voltages around a closed path (or loop) is zero. Mathematically,



$$\sum_{m=1}^{M} v_m = 0$$

KVL is based on **the law of conservation of energy**. An alternative form of KVL is

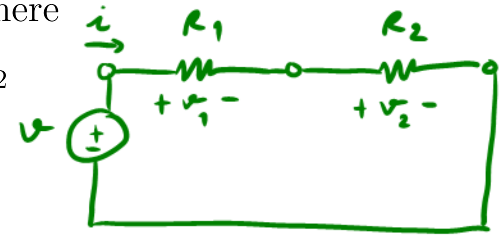
Sum of voltage drops = Sum of voltage rises.



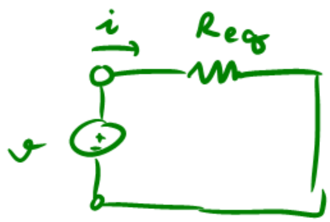
2.4. Series Resistors and Voltage Division

When two resistors R_1 and R_2 ohms are connected in series, they can be replaced by an *equivalent* resistor R_{eq} where

$$R_{eq} = R_1 + R_2$$



Ohm's law = $v_1 = iR_1$, $v_2 = iR_2$ (KCL)



KCL: $-v + v_1 + v_2 = 0$

$v = v_1 + v_2 = iR_1 + iR_2 = i(R_1 + R_2) = i(R_{eq})$

Voltage Divider: If R_1 and R_2 are connected in series with a voltage source v volts, the voltage drops across R_1 and R_2 are

$$v_1 = \frac{R_1}{R_1 + R_2}\, v \qquad \text{and} \qquad v_2 = \frac{R_2}{R_1 + R_2}\, v$$

Note: The source voltage v is *divided* among the resistors in direct proportion to their resistances.

$i = \frac{v}{R_1 + R_2}$

$v_1 = i \times R_1 = v \frac{R_1}{R_1 + R_2}$

In general, for N resistors whose values are $R_1, R_2, \ldots, R_N$ ohms connected in series, they can be replaced by an *equivalent* resistor R_{eq} where

$$R_{eq} = R_1 + R_2 + \cdots + R_N = \sum_{j=1}^{N} R_j$$

If a circuit has N resistors in series with a voltage source v, the jth resistor R_j has a voltage drop of

$$v_j = \frac{R_j}{R_1 + R_2 + \cdots + R_N}\, v$$

2.5. Parallel Resistors and Current Division

When two resistors R_1 and R_2 ohms are connected in parallel, they can be replaced by an *equivalent* resistor R_{eq} where

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

or

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

Current Divider: If R_1 and R_2 are connected in parallel with a current source i, the current passing through R_1 and R_2 are

$$i_1 = \frac{R_2}{R_1 + R_2}\, i \qquad \text{and} \qquad i_2 = \frac{R_1}{R_1 + R_2}\, i$$

Note: The source current i is *divided* among the resistors in inverse proportion to their resistances.

In general, for N resistors connected in parallel, the *equivalent* resistor R_{eq} is

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N}$$

It is often more convenient to use conductance rather than resistance when dealing with resistors in parallel. The equivalent conductance

$$G_{eq} = \frac{1}{R_{eq}} = G_1 + G_2 + \cdots + G_N$$

where $G_j = 1/R_j$, $j = 1, 2, \ldots, N$.

2.6. Practical Voltage and Current Sources

An ideal voltage source is assumed to supply a constant voltage. This implies that it can supply very large current even when the load resistance is very small.

However, a practical voltage source can supply only a finite amount of current. To reflect this limitation, we model a practical voltage source as an ideal voltage source connected in series with an internal resistance r_s, as follows:

Similarly, a practical current source can be modeled as an ideal current source connected in parallel with an internal resistance r_s.

2.7. Measuring Devices

Ohmmeter: measures the resistance of the element.
Important rule: Measure the resistance only when the element is disconnected from circuits.

Ammeter: connected in **series** with an element to measure current flowing through that element. Since an ideal ammeter should not restrict the flow of current, (i.e., cause a voltage drop), *an ideal ammeter has zero internal resistance.*

Voltmeter:connected in **parallel** with an element to measure voltage across that element. Since an ideal voltmeter should not draw current away from the element, *an ideal voltmeter has infinite internal resistance.*