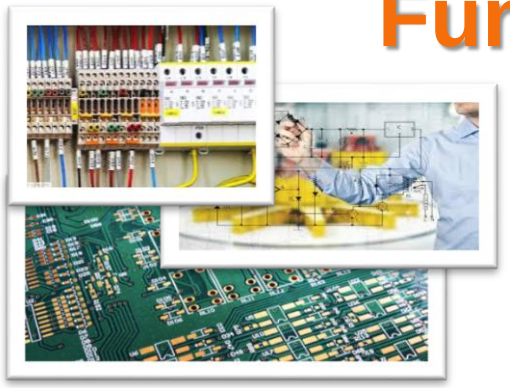
Fundamentals of Electric Circuits



DC Circuits

Chapter 1. Basic concepts

1.1. Introduction
1.2. Systems of Units
1.3. Charge and Current
1.4. Voltage
1.5. Power and Energy
1.6. Circuit elements

1 Basic Concepts

1.1. Introduction

+ Models for electromagnetic systems/ electromagnetic interactions:

electromagnetic model → *electromagnetic theory*

electric circuit model → *electric circuit theory*

+ Electric Circuit Model:

+ Information: at several points in system

+ Based on Kirchhoff's current and voltage laws

+ Basic elements of circuits: R, L, C and sources

→ Each physical (electromagnetic) phenomenon: represented by one element → the *waves transmission* in system is *not observed*

→ *Distribution* of electromagnetic quantities *in space* is ignored

1 Basic Concepts

1.1. Introduction

+ **Conditions** to represent/approximate an electromagnetic system by an electric circuit model

→ The wave length is much greater than the dimension of the system

→ The electrical conductivity of wires or electrical material in the system is much greater than that of outside environment

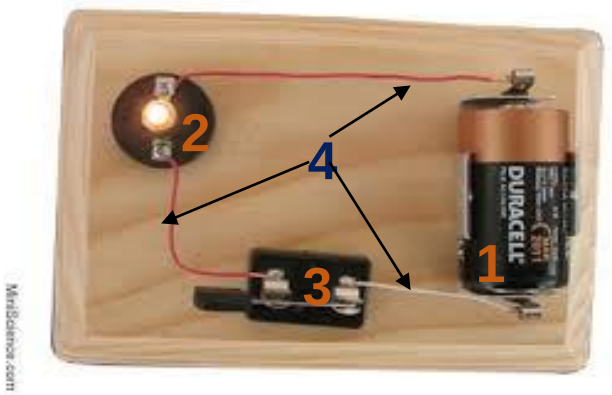
+ **An electric circuit (model):**

Interconnection of an **infinite set** of components/circuit elements to represent exactly the electromagnetic interactions in considered object

+ **Featured variables** in an electric circuit: electric **current** and **voltage**

Basic Concepts

1.1. Introduction

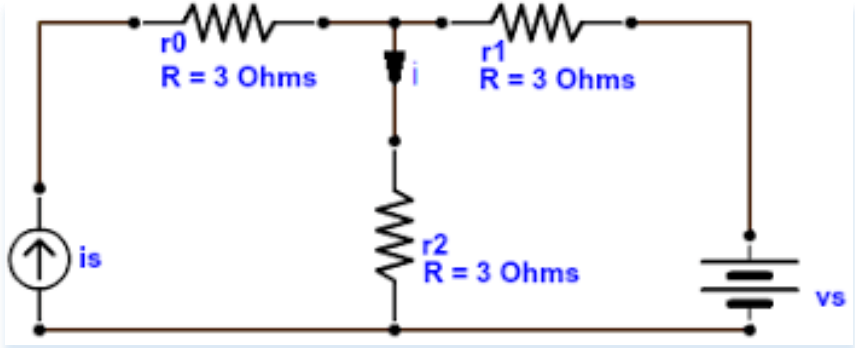


+ An example of a (real) simple electric circuit:

1 - a battery
2 - a lamp
3 - a contact
4- connecting wires

+ Geometric elements of an electric circuit (a model in general):

→ Circuit elements
→ **Branch**
→ **Mesh** (loop)
→ **Node**



+ Analysis of an electric circuit:

To know how

→ The circuit responds to given inputs

→ The interconnected elements and devices in the circuit interact

1 Basic Concepts

1.1. Introduction

+ A basic *circuit element*:

→ Represents one **single physical phenomenon**

→ Modeled as an **one port element**

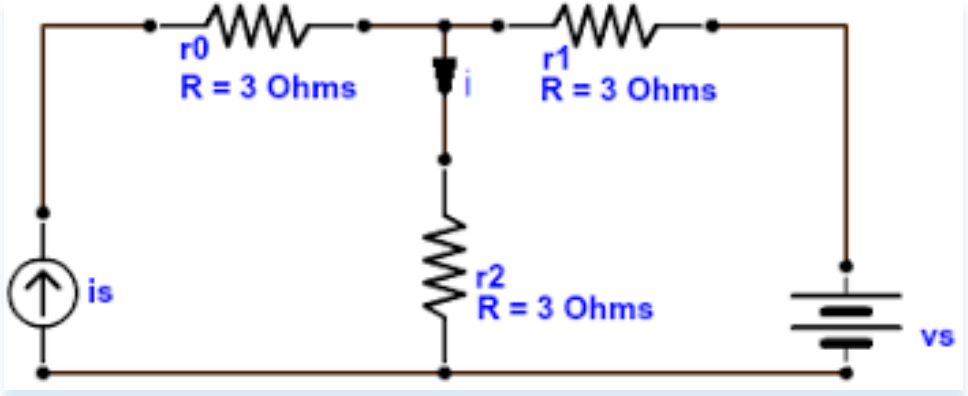
→ Having 2 *featured variables* at port: **current** and **voltage**

→ Connecting to other parts of the circuit through two **poles** of port

+ Following sections:

Introduction to

→ System of units
→ Charge and Current
→ Voltage
→ Power and Energy
→ Circuit Elements



1.2. System of Units

+ The International System of Unit (**SI**)

→ Seven principal units

→ The units of all other physical quantities can be derived from these 7 basic units

+ The derived units in the SI

→ formed by powers, products or quotients of the base units

→ unlimited in number

→ Derived units are associated with derived quantities

SI base units

Quantity	Basic unit	Symbol
Length	Meter	m
Mass	Kilogram	Kg
Time	Second	s
Electric current	Ampere	A
Thermodynamic temperature	Kelvin	K
Amount of subtance	Mole	mol
Luminous intensity	Candela	cd

For example: velocity → derived from the base quantities of time and length, so in SI the derived unit is meters per second (symbol m/s)

1.2. System of Units

+ Derived units for some electromagnetic quantities

Quantity	Unit	Symbol
Admittance	siemen	S
Angular frequency	radian/second	rad/s
Capacitance	farad	F
Charge density	Coulomb/meter^3	C/m^3
Conductance	siemen	S
Conductivity	siemen/meter	S/m
Energy	joule	J
Force	newton	N
Frequency	hertz	Hz
Impedance	ohm	Ω
Inductance	henry	H
Magnetomotive force	ampere-turn	A^{0}t
Permeability	henry/meter	H/m
Permittivity	farad/meter	F/m
Power	watt	W
Reluctance	henry^{-1}	H^{-1}

1.3. Charge and Current

+ Charge: an electrical property of the atomic particles of which matter consists, measured in coulombs (C)

+ Each atom consists of electrons, protons and neutrons

Charge of an *electron*: -1.602×10^{-19} C

Charge of a *proton*: 1.602×10^{-19} C

+ **Law of conservation of charge**:

Charge can neither be created nor destroyed, only transferred

1.3. Charge and Current

+ Electric charge is mobile

→ can be transferred from one place to another

→ can be converted to another form of energy

+ When a conducting object is connected to a source (a battery for example)

→ Positive charges move in one direction (to negative pole)

→ Negative charges move in the opposite direction (to positive pole)

creat an electric curent

+ The current in metallic conductors is due to negative charges movement (free electrons)

→ the current flow (direction) is taken as the movement of positive charge

+ *Electric current* *is the time rate of change of charge, measured in amperes (A)*

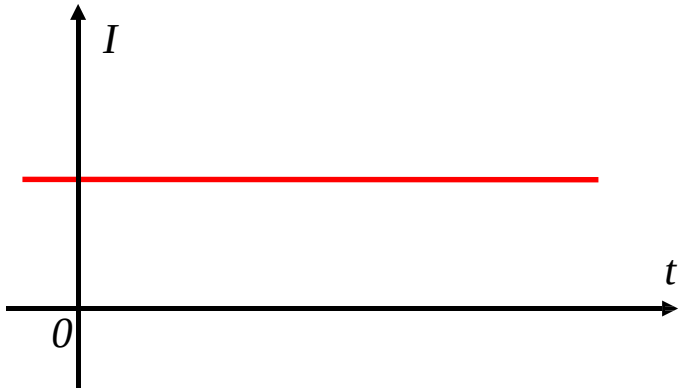
$$i = \frac{dq}{dt} \quad ; \quad [A] = \frac{[C]}{[s]}$$

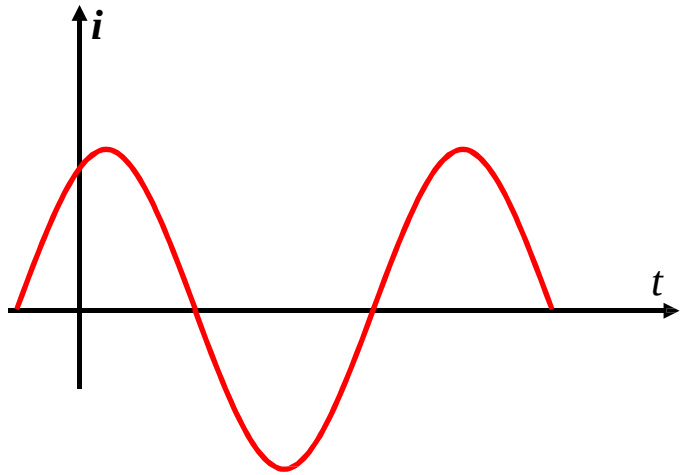
1.3. Charge and Current

+ Two common types of electric current

→ ***Direct current*** (DC) : a current that remains constant with time (I)

→ ***Alternating current*** (AC) : a current that varies sinusoidal with time (i)





+ Note:

Positive current

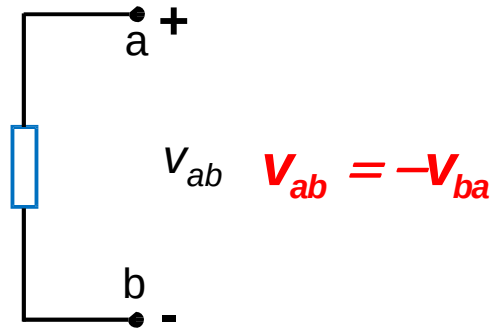
Negative current

1.4. Voltage

+ In order to move free electrons in a conductor in a particular direction → requires some work or energy transfer → needs *external electromotive force (emf)*, as known as *voltage* or *potential difference*

+ ***Voltage*** (or potential difference) is the energy required to move an unit charge through an element, measured in volts (V)

$$v_{ab} = \frac{dw}{dq} \quad ; \quad [V] = \frac{[J]}{[C]} = \frac{[Nm]}{[C]}$$



+ Two types of voltage:

→ **DC voltage**: produced by a DC source/generator (a battery for example)

→ **AC voltage**: produced by an AC generator

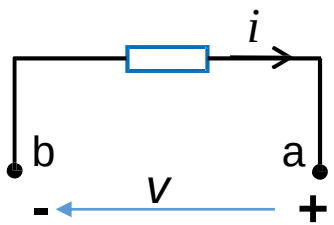
1.5. Power and Energy

+ ***Power*** is the work which can be done in an unit of time (indicating the capacity to do work), measured in watts (W)

$$p = \frac{dw}{dt} = \frac{dw}{dq}.\frac{dq}{dt} = vi$$ (instantaneous power)

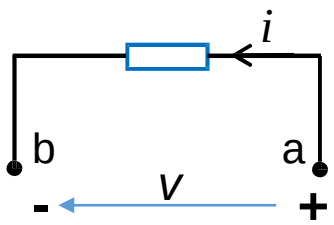
+ Sign convention

If the current enters through the negative terminal of an element → power has *negative sign*



p = -vi

power is being supplied by the element



p = vi

power is being delivered to the element

1.5. Power and Energy

+ Law of conservation of power

$$\sum p = 0$$

In an electric circuit, total power supplied by active elements (sources) equals to that received by passive elements (loads)

+ Energy is the amount of power accumulated in a duration of time (indicating the time rate of expending or absorbing energy), measured in Joules (J)

$$w = \int_{t_0}^{t} p\,dt = \int_{t_0}^{t} vi\,dt$$

Energy is also measured in Watt-hours (Wh) or kilowatt-hour (kWh)

1 Wh = 3,600 J

1.6. Circuit Elements

+ Types of circuit elements

→ Passive elements: not be able to generate energy

resistors, capacitors, inductors

→ Active elements: to be able to generate energy

voltage sources, current sources

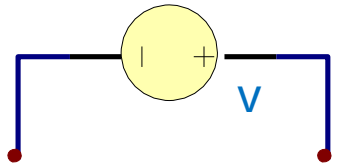
+ Two kinds of sources

→ Independent sources

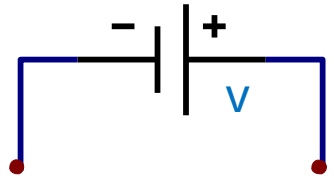
→ Dependent sources

1.6. Circuit Elements

+ An ideal **independent voltage source**: maintain its terminal voltage (both value and time varying feature) and delivers to the circuit whatever necessary current

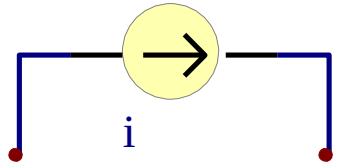


AC or time varying independent voltage source



DC independent voltage source

+ An ideal **independent current source**: provides a specified current (both value and time varying feature) completely independent of the voltage across the source



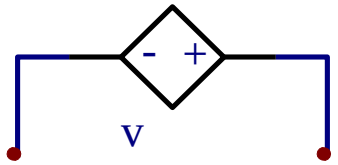
Independent current source (DC and AC)

Note: the arrow indicates the direction of current i

1.6. Circuit Elements

+ An ideal **dependent** (or controlled) **source**: an active element in which the source quantity is controlled by another voltage or current

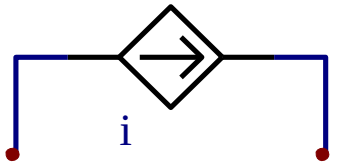
→ A voltage-controlled voltage source (VCVS)
→ A current-controlled voltage source (CCVS)
→ A voltage-controlled current source (VCCS)
→ A current-controlled current source (CCCS)



Dependent voltage source

+ Dependent sources are useful in modeling real physical elements:

Operational amplifiers
Transistors
Integrated circuits



Dependent current source

→ Circuit analysis: the process of determining voltages across (or the currents through) elements of the circuit