Lecture 2: Electric Circuit Variables

ELEC1111 Electrical and Telecommunications Engineering

CONTENTS

1. INTRODUCTION

- Electricity – the physical phenomenon arising from the existence and interaction of electric charge.

- Charge cannot be created or destroyed – we do build electrical devices to manipulate the charge in many different ways, so that they do things like convey electrical energy or information ➔ Electrical Engineering.

- Practical electrical devices are made up from an interconnection (network) of many simple electrical components.

- Usually, the network contains at least one closed path (loop) so that an electric current may flow ➔ such a network is called an **electric circuit**

1. INTRODUCTION

- For analysis, we need to be able to describe a circuit's behaviour. This is done by creating mathematical models for the various components in the circuit. Models can be simple or complex and complicated.

- A basic circuit element i.e. resistor, capacitor, inductor, voltage source, current source, has 2 terminals.

- Characteristic is described by the voltage/current relationship

- Interconnections in a circuit allow the elements to share currents and voltages so they can interact with each other.

2. SYSTEMS OF UNITS

- ✓ Need a consistent system of units to describe electrical quantities (e.g. voltage, current) in the circuit.
- ✓ SI Units – International System of Units, built upon the seven base or fundamental units below.

Quantity	Unit Name	Unit Symbol
Length	Metre	m
Mass	Kilogram	kg
Time	Second	s
Temperature	Kelvin	K
Electric current	Ampere	A
Amount of substance	Mole	mol
Luminous intensity	candela	Cd

2. SYSTEMS OF UNITS

✓ Units for other physical quantities by combining base units.

Quantity	Unit Name	Formula	Symbol
Frequency	hertz	s^{-1}	Hz
Force	newton	$kg.m/s^2$	N
Energy (work)	joule	N.m	J
Power	watt	J/s	W
Electric Charge	coulomb	A.s	C
Electric potential	volt	W/A	V
Resistance	ohm	V/A	Ω
Conductance	siemens	A/V	S
Capacitance	farad	C/V	F
Magnetic flux	weber	V.s	Wb
Inductance	henry	Wb/A	H

2. SYSTEMS OF UNITS

✓ Multiples/prefixes

Factor	Name	Symbol
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f

Factor	Name	Symbol
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deka	da

3. CHARGE

- ✓ Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs (C).

- ✓ Charge can be positive or negative.
  - ✓ Proton – most elementary positive charge
  - ✓ Electron – most elementary negative charge

- ✓ The charge e on one electron is negative and equal in magnitude to 1.602×10^{-19} C which is called electronic charge. The charges that occur in nature are integral multiples of the electronic charge.

3. CHARGE

- ✓ Charge = quantity of electricity
- ✓ Unit: coulomb, C
- ✓ Symbol:

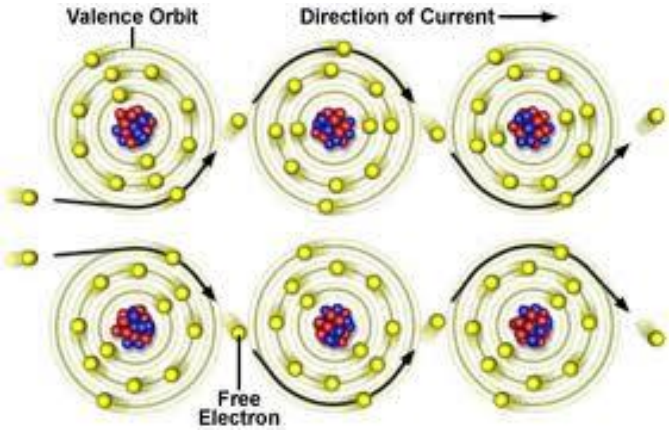
  Q = constant quantity

  $q(t)$ or q = instantaneous value

4. CURRENT

✓ Electric charge is mobile – movement of charge from one place to another results in a transfer of energy.

✓ Electric current is defined as the time rate of change of charge past a given point.



http://ajitvadakayil.blogspot.com.au/2010/06/basics-for-chemical-tankerman-capt-ajit.htm

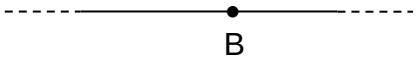
✓ Measured in amperes, A.

✓ Symbol for current ➔ i or I

✓ By definition: $i \triangleq \frac{dq}{dt}$

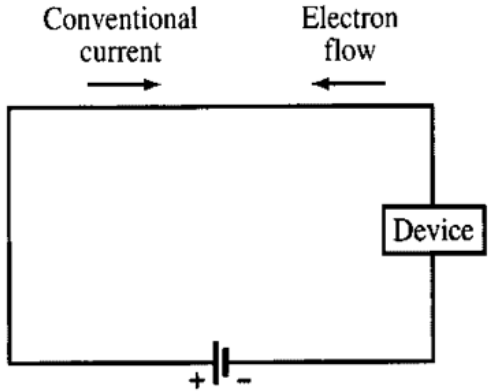
So 1 ampere is 1 coulomb per second

<u>Example</u>: The current flows through the point B of the electrical cable below is 2A. How many electrons pass through B in 1 second?



4. CURRENT

✓ **Convention** – despite current flow in a metallic conductor being due to electron (negative charge) motion, the flow of current is represented as a flow of **positive** charge.



✓ Current needs to be described by a value as well as a direction.

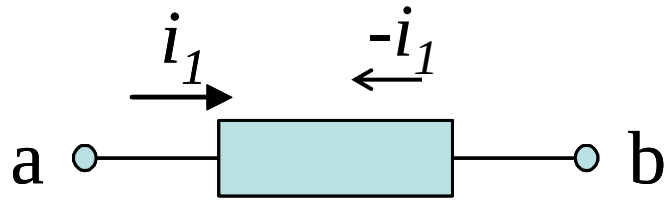
So, if $i = 5A$, then it means a net positive charge of 5 C is moving from terminal a to terminal b every second.

4. CURRENT

If i_1 is +3 Amps then we have:

If i_1 is –6 Amps then we have:

Note: currents in opposite directions



4. CURRENT

Direct Current (DC)

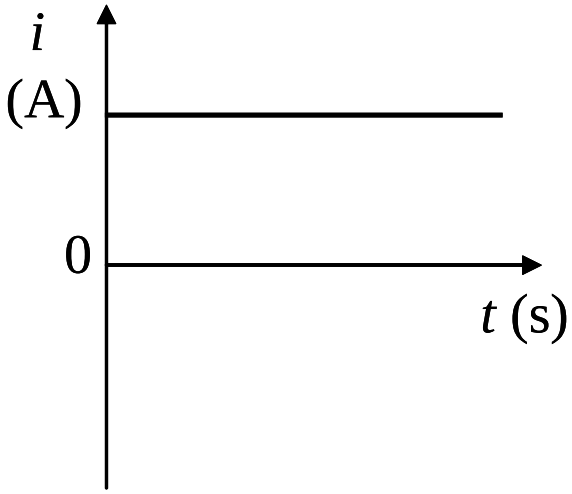
- ✓ A current that remains constant with time: *I*

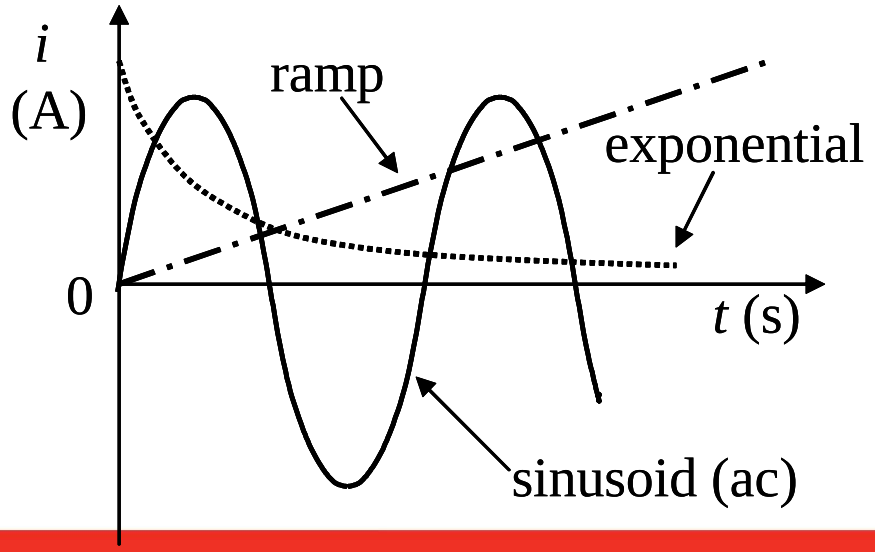
Time-varying current

- ✓ Represented by the symbol *i* or *i*(*t*)

Alternating Current (AC)

- ✓ A time-varying current that varies sinusoidally





Direct current (dc)

Time-varying current

4. CURRENT

✓ To determine charge from current:

$$i \triangleq \frac{dq}{dt} \quad \rightarrow q = \int_{-\infty}^{t} i\, d\tau = \int_{0}^{t} i\, d\tau + q(0)$$

where $q(0)$ is the charge at $t = 0$ and $i(t) = 0$ for $t \leq 0$.

Example:

Determine the total charge transferred over the time interval of $0 \leq t \leq 10s$ when the current $i(t) = 0.5t$

Solution

$$q = \int_{0}^{10} i\, d\tau =$$

5. VOLTAGE

- ✓ The **voltage** (or **potential difference**) across a circuit element is defined as a measure of the energy (work) involved when moving charge through the element.

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

v – voltage; *w* – energy; *q* – charge; (joules/coulomb)

- ✓ So Voltage is the force or push of electricity, also Electro-Motive Force (EMF)
- ✓ Units of volts, V.
- ✓ Symbol for voltage ➔ *v* or *V*

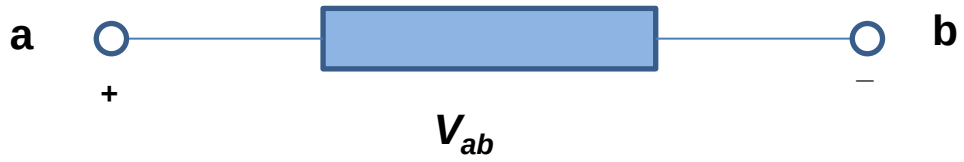
5. VOLTAGE

- ✓ We need to distinguish between the energy supplied *to* an element and energy that is supplied *by* the element.
  - ➢ So we assign one terminal of the element positive with respect to the other.

- ✓ Convention:
  - ✓ If terminal *a* is positive with respect to terminal *b*, and a positive current enters terminal *a*, then an external source must expend energy to establish this current.
    - ✓ We say that the device between *a* and *b* **dissipates** energy

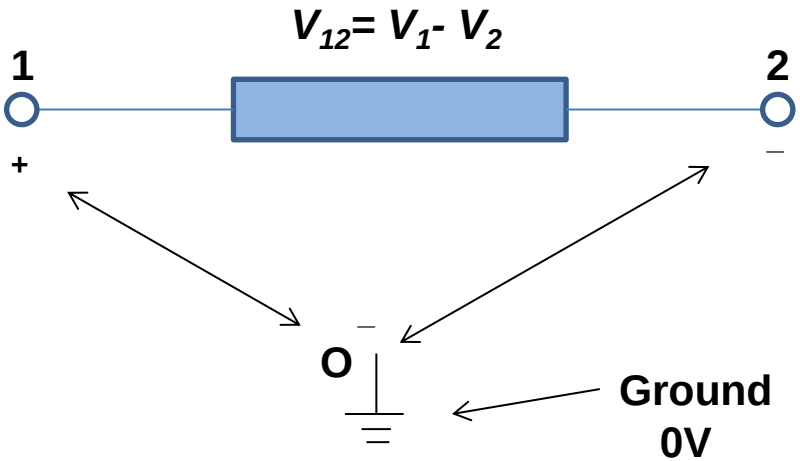
5. VOLTAGE

- ✓ Thus to fully describe a voltage across an element, we require assigning:
  - ✓ A "+ terminal" and a "- terminal", as well as
  - ✓ A value (or variable name) – this denotes the voltage at the "+ terminal" with respect to the "- terminal"



- ✓ Example: if V_{ab} = 7V, then we say terminal *a* is 7V positive with respect to terminal *b*. Or the voltage drop from *a* to *b* is 7V.
- ✓ V_{ba} = ?

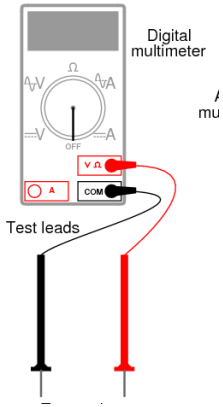
5. VOLTAGE



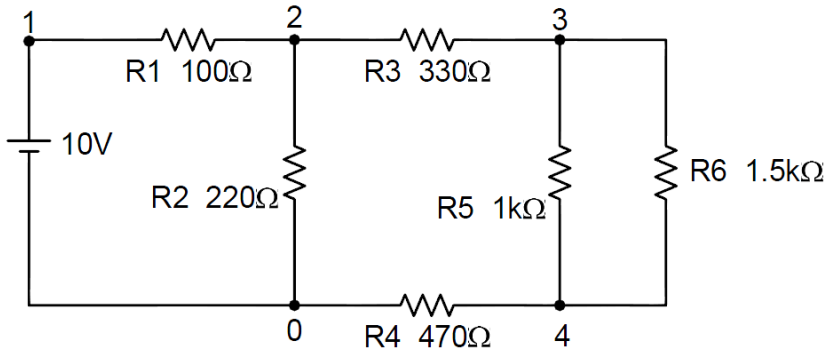
$V_{12}= V_1- V_2$

$V_1= V_1- V_o$

$V_2= V_2- V_o$



Example: *A question in lab 2 -*
Measure the voltages $V_{12,}$ V_{23}, V_{34} and V_1, $V_{2,}$ V_3, V_4, at laboratory



Note: *The value of V_1, $V_{2,}$ V_3, V_4, $V_{12,}$ V_{23}, V_{34} should be computed and reported in lab book before lab time*

6. POWER & ENERGY

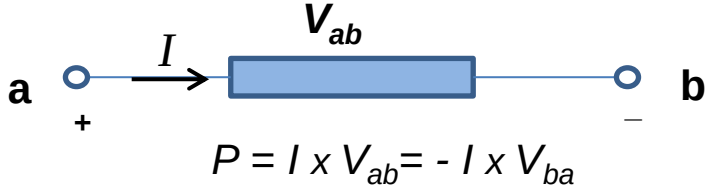
- ✓ **Power** – time rate of change of expending or absorbing energy

$$p \triangleq \frac{dw}{dt}$$

But also:

$$\frac{dw}{dt} = \frac{dw}{dq} . \frac{dq}{dt} \rightarrow v.i$$

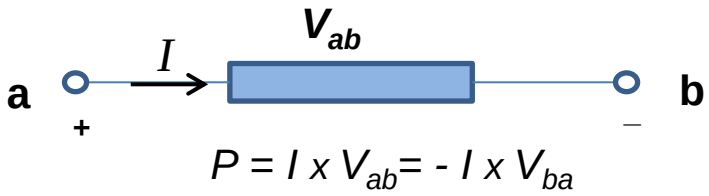
- ✓ Power is product of voltage across the element and the current flowing through it.



- ✓ Units of watts, W.
- ✓ Symbol for power ➔ p or P

6. POWER & ENERGY

- ✓ **Passive sign convention** – defined when current enters the positive terminal of an element and $p = +v.i$. If current enters through the negative terminal, $p = -v.i$.



6. POWER & ENERGY

- ✓ **Energy –** assuming passive convention

$$w = \int_{-\infty}^{t} p\, d\tau = \int_{0}^{t} p\, d\tau$$

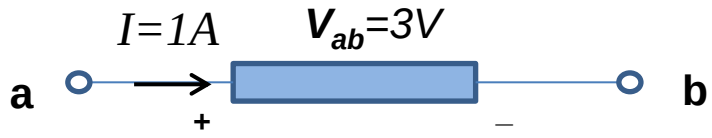
if element only receives power for $t \geq 0$.

- ✓ Unit of energy is Joule, J.
- ✓ Symbol, *w* or *W*.

- ✓ Alternatively, electricity utilities use kilowatt-hour

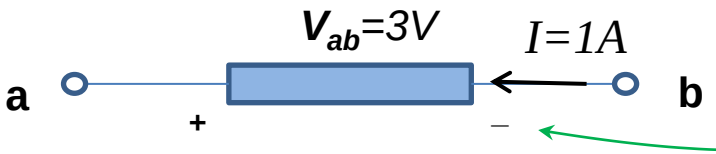
$$1\ kWh = \left(\frac{10^3 J}{s}\right)(3600s) = 3.6MJ.$$

6. POWER – ABSORB OR SUPPLY



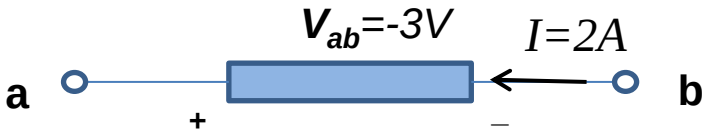
$P = I \times V_{ab} = 1 \times 3 = 3W > 0$

*The circuit element **absorbed** the power of 3W OR the power **dissipated** on the circuit element is 3W*



$P = -I \times V_{ab} = -1 \times 3 = -3W < 0$

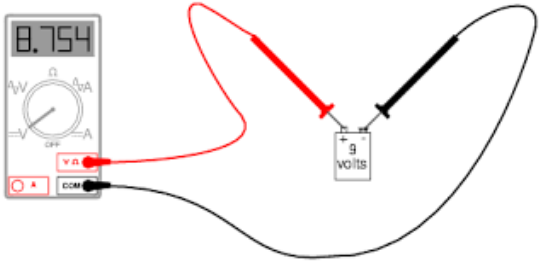
*The circuit element **supplies** (or **generates**) the power of 3W*



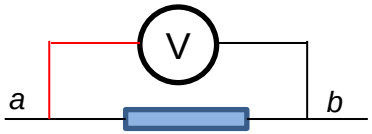
P =

Is the circuit element absorbs or generates power?

7. MEASURING VOLTAGE & CURRENT

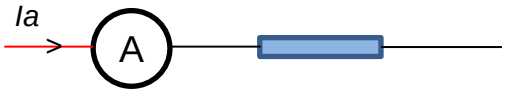


- ✓ **Voltmeter –** instrument for measuring voltage.
  - ✓ Voltage is measured *across* its terminals.
  - ✓ Current *through* its terminals is negligible.

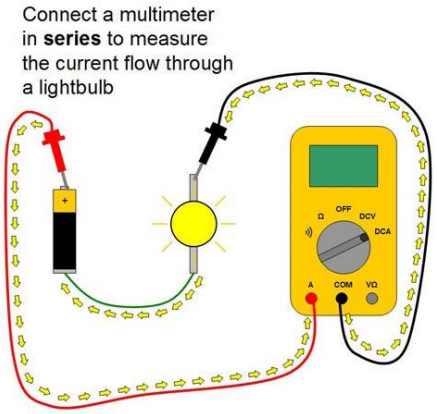


Measure V_{ab}

- ✓ **Ammeter –** instrument for measuring current.
  - ✓ Current is measured *through* its terminals.
  - ✓ Voltage *across* its terminals is negligible.



Measure I_a

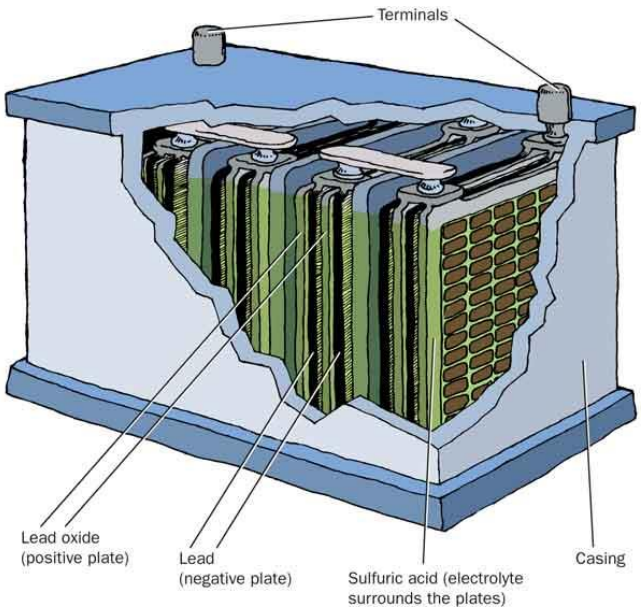


- ✓ **Multimeter –** a multi-function instrument to measure voltage, current, resistance, ….

- ✓ Refer to video lectures at for multimeter operations http://eemedia.ee.unsw.edu.au/Laboratory/index.htm

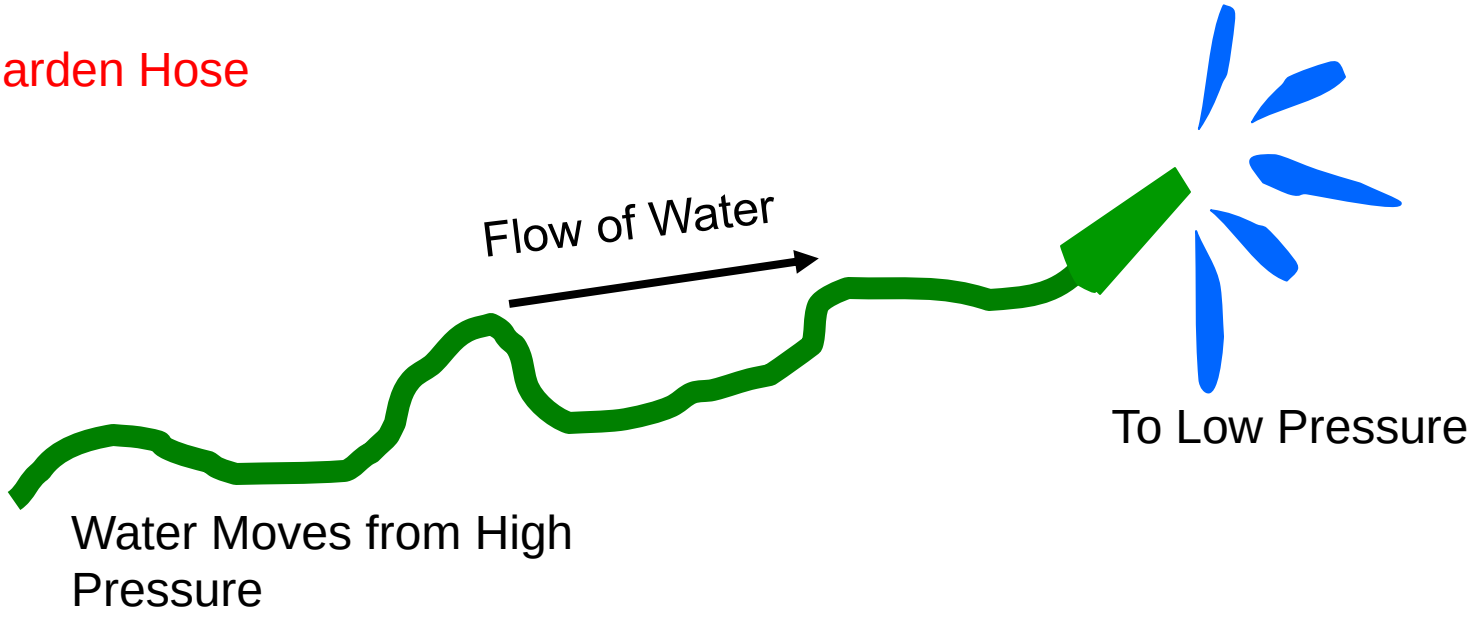
Analogy

- Dam, reservoir → **Battery**
- Water → **Charge**
- Flow rate → **Current**
- Water pressure → **Potential energy (Voltage)**



Analogy

A Garden Hose



The same thing occurs in an Electrical Wire