Introduction to Electric Circuits

ENAE 362

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What do you remember about charge?

Charge, q

- Fundamental property of matter
- Conserved quantity: charged is neither created or destroyed
- Two types: positive and negative
- Like charges repel, opposite charges attract
- Units: Coulombs, C
- Charge is quantized; smallest unit of charge is the electron
- A single electron has a negative charge of $-1.602 \times 10^{-19} C$

What do you remember about current?

Current, i

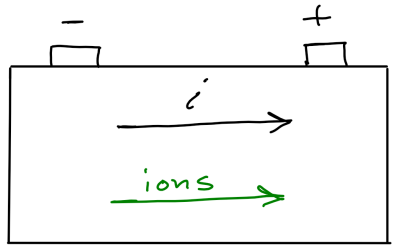
"Current" is charge in motion.

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

- Units: Amperes, A
- Often abbreviate Amperes as Amp
- 1 A = 1 C/s
- Sign convention: i is positive in the direction positive charge movement

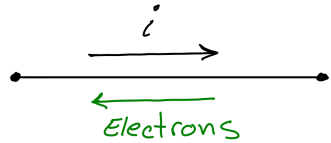
Current flow through battery

In electrochemical batteries, current flow is due to the movement of positive ions.



Current flow through a wire

Current flow through a wire is due to the movement of electrons. Electrons carry negative charge. Thus, the direction of positive current flow is in the opposite direction of electron flow.



NOTE:

- In circuit analysis, the effect of electron motion is equivalent to the movement of positive charge in the opposite direction.
- In your lab manuals, the author sometimes chooses to draw current flow in the direction of electron movement.

Range of Current

Typical orders of magnitude in Amps

10^{-12}	Synaptic current in brain cells
10^{-8}	Current in computer memory
10^{-3}	Threshold of sensation in humans
10^{-1}	Fatal to humans
10^{1}	Common household appliances (vacuum cleaners)
10^{3}	Large industrial motors
10^{4}	Lightning bolt

What do you remember about voltage?

Voltage, v

"Voltage" is an electric potential directly related to the motive force required to move charge through a conductor.

- Voltage is to current as pressure is to mass flow rate.
- Always measured relative to some reference point; never work with absolute values of voltage.
- Units: Volt, V

Range of Voltage

Typical orders of magnitude in Volts:

10^{-8}	Antenna of radio receiver
10^{-6}	Voltage between two points on human scalp
10^{-3}	Voltage produced by heart across human chest
10^{0}	Common DC electronics (1.5 V - 12 V)
10^{2}	House wiring (120V)
10^{3}	Large industrial motors
10^{5}	Cross-country transmission lines
10^{8}	Lightning

Lumped Circuit Modelling

In this class, we will assumed a “lumped circuit model.”

- Idealize circuit as a network of “elements” connected by ideal conductors.
- Each circuit element has a well defined input-output behavior
- Ignore the possibility of interference between circuit elements
- Real-world circuit components are represented by one or more idealized circuit elements.
  - Real-world resistance of electrical connections will be modeled by a resistor circuit element.
  - A light bulb can be modeled as a resistor

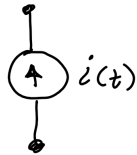
Basic types of circuit elements

- Active elements
  - Independent sources
  - Dependent sources
- Passive elements

Active Element: Independent sources

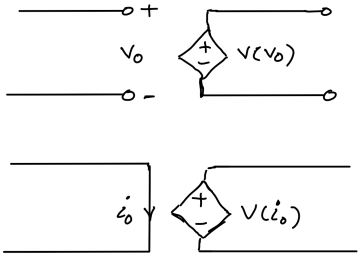
Voltage source (e.g. battery, generator):

Current source (e.g. photovoltaic cells, LED driving circuit):

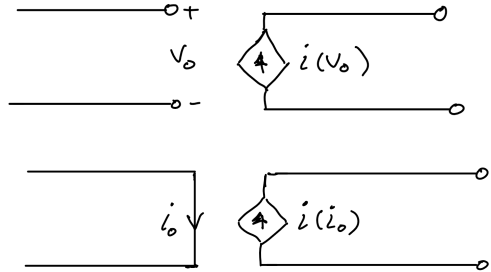


Active Element: Dependent Sources

Voltage sources:



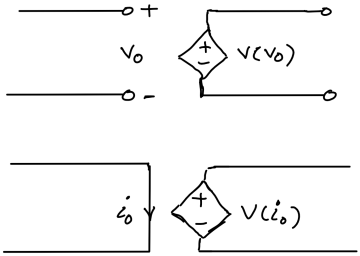
Current sources:



We'll encounter this type of circuit element when discussing operational amplifiers. Don't worry too much about this now.

Active Element: Dependent Sources

Voltage sources:



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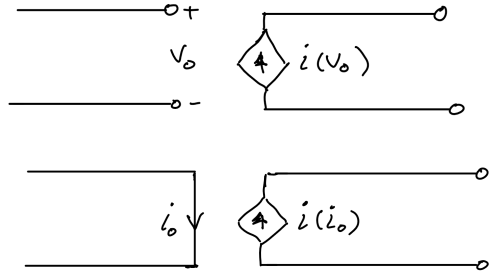

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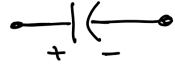
Passive Elements

Common examples of passive elements:

- Resistor, $v = iR$

- Inductor, $v = L\frac{di}{dt}$

- Capacitor, $i = c\frac{dv}{dt}$

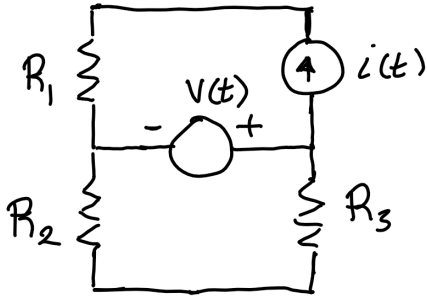


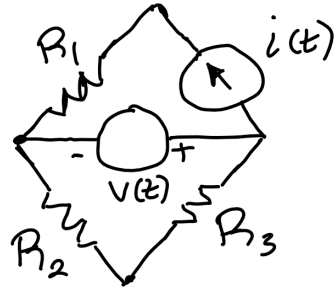
We'll discuss these more later.

Circuit Topology

- “Topology” is a branch of geometry that concerns itself with how things are connected (or not connected). It is what remains after to remove dimensional quantities like size and shape.
- In (lumped) circuit analysis, we only care about the topology of a circuit; i.e. how elements are connected.
- Basic topological elements of a circuit: node, branch, loop, and mesh

Example: Are these two circuits the same?

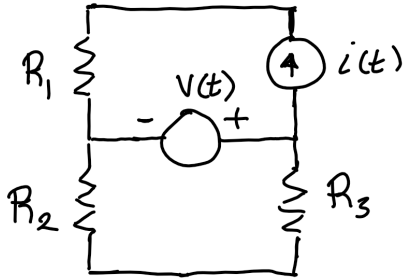




Node

A circuit “node” is a point of connection between two or more circuit elements.

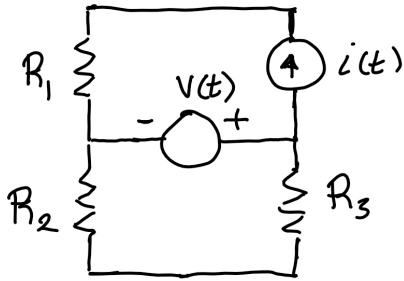
Example: How many nodes?



Loop

A circuit “loop” is any closed path through a circuit in which no node is crossed more than once.

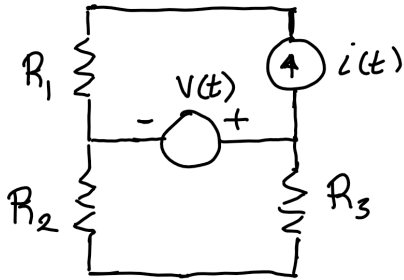
Example: How many loops?



Mesh

A circuit “mesh” is any loop that does not contain another loop.

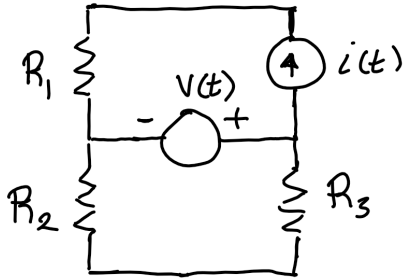
Example: How many meshes?



Branch

A circuit “branch” is a portion of the circuit containing only a single element and the nodes at each end of the element.

Example: How many branches?



Circuit Laws

Laws governing the behavior of a circuit:

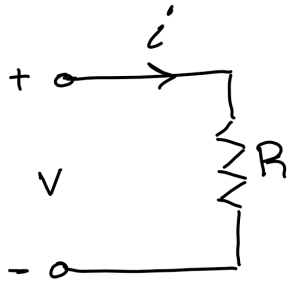
1. Ohm's Law
2. Kirchhoff's First Law
3. Kirchhoff's Second Law

Ohm's Law

The voltage across a resistance is directly proportional to the current flowing through it.

- Resistance is measured in Ohms, Ω
- 1Ω = 1 V/A

$$v = iR$$



Power loss due to resistance

Power

$$P = vi$$

Substitute Ohm's Law, $v = iR$,

$$\begin{aligned} P &= vi \\ &= (iR)i \\ &= i^2 R \end{aligned}$$

or

$$\begin{aligned} P &= vi \\ &= v(v/R) \\ &= \frac{v^2}{R} \end{aligned}$$

Kirchhoff's First Law

The algebraic sum of the currents entering any node is zero.

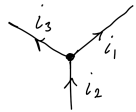
$$\sum_j i_j = 0$$

Also known as Kirchhoff's Current Law (KCL).

NOTE: When applying KCL, it is often easier think in terms of

$$\sum_{in} i - \sum_{out} i = 0$$

Example:



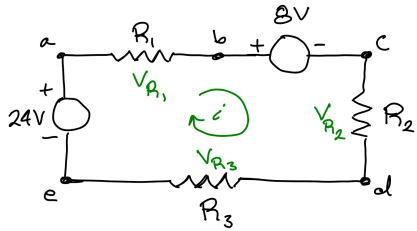
$$i_2 - i_1 - i_3 = 0$$

Kirchhoff's Second Law

The algebraic sum of voltages around any loop is zero.

Also known as Kirchhoff's Voltage Law (KVL)

Example: Assuming clockwise current flow...



$$-v_{R_1} - 8V - v_{R_2} - v_{R_3} + 24V = 0$$