CLASS 3: ELECTRICAL FUNDAMENTALS

ENGR 102 – Introduction to Engineering

Fundamental Quantities

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Fundamental Electrical Quantities

- **GOAL**: begin to understand the function of basic electrical circuits

- **REQUIREMENT**: become familiar with fundamental electrical concepts and quantities:
  - *Voltage* or *potential*
  - *Charge*
  - *Current*

Electrical Charge

- Electrical energy results from *charge differentials*
  - Different amounts of *positive* and *negative electrical charge* between two locations
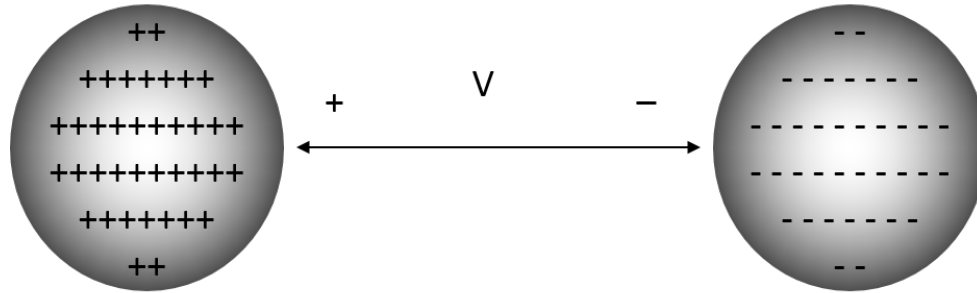   - E.g., between battery electrodes

- *Negative electrical charge*
  - *Electrons* are the carriers of negative electrical charge

- *Positive electrical charge*
  - *Holes* are the carriers of positive electrical charge
  - The absence of an electron

- *Units of charge*: coulombs (C)
  - Charge of one electron: 1.6×10^{-19} C

Electrical Potential

□ **Potential** or **voltage** or **electromotive force** (emf)

  ◻ A measure of electrical energy

  ◻ The energy required to move one unit of electrical charge from one point to another

    ▪ Units of potential: volts (V)
    ▪ Units of electrical charge: coulombs (C)
   ▪ Units of energy: joules (J)

$$1V = 1\frac{J}{C}$$

Electrical Potential

- Electrical potential is a ***differential quantity***
  - Voltage ***between*** two points in a circuit
  - Voltage between a point and a ***ground reference***

- No such thing as an *absolute* voltage at a location, but…
  - We do talk about ***node voltages***
    - Always referenced to ground
  - For example,
    - Node voltages:
      $$V_a = 10\ V, \quad V_b = 5\ V$$
    - Differential voltage:
      $$V_{ab} = V_a - V_b = 5\ V$$
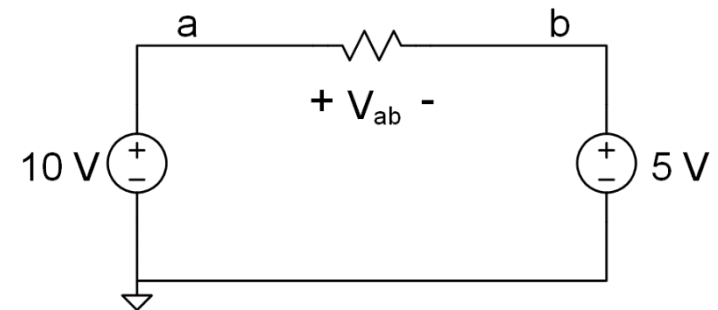
Electrical Current
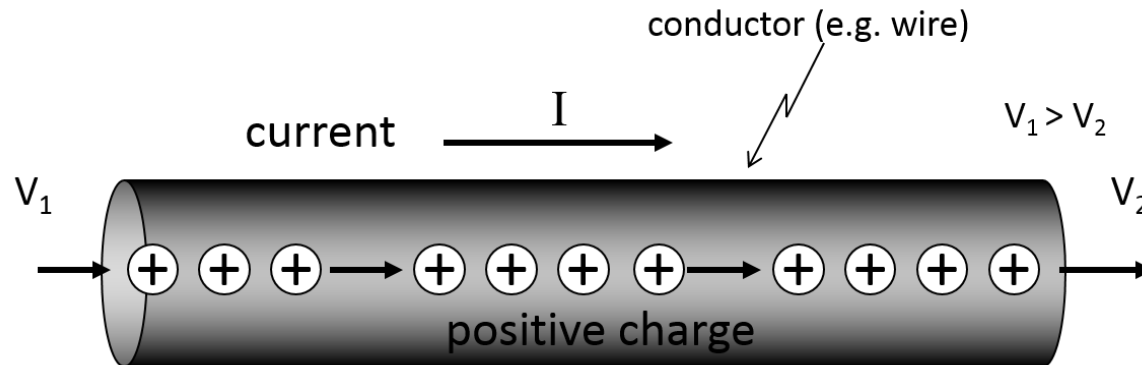
- **Current** (I) is the flow of positive charge
  - Voltage is the driving potential
  - Units: amperes or amps (A) – coulombs per second (C/s)
    - A **rate** of charge flow:

$$1A = 1\frac{C}{s}$$

  - Current wants to flow from high to low potential
  - Analogous to fluid flow or heat flow
    - Fluid flows from high to low pressure
    - Heat flows from high to low temperature

Current – what's really flowing?

conductor (e.g. wire)

current $\quad$ I

$V_1 > V_2$

V_1 $\qquad$ V_2
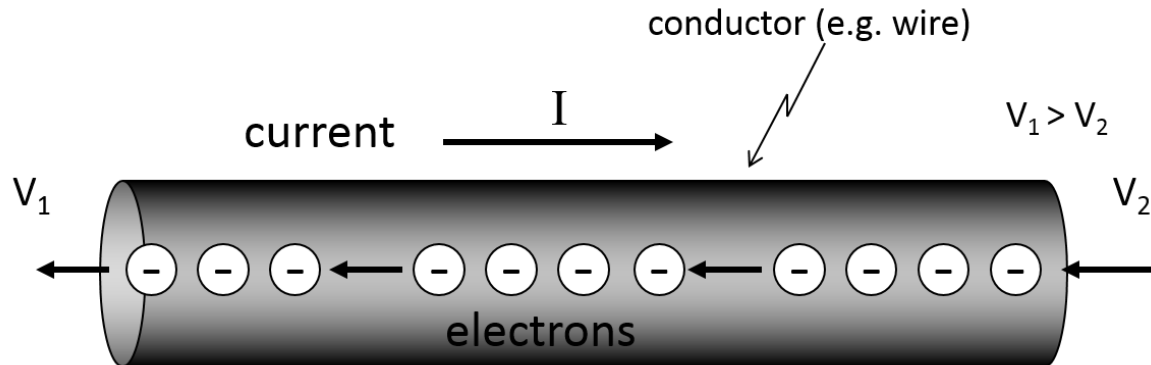
electrons

- Current is defined as the ***flow of positive charge***
- Really, current is the ***flow of negatively-charged electrons in the opposite direction***
  - Electrons flow from low potential to high potential
  - Negative charge flow in one direction is equivalent to positive charge flow in the opposite direction

Electrical-Mechanical Analogies

□ Electrical systems are analogous to:
  ▫ *Fluid systems*
  ▫ *Thermal systems*

| Domain	Driving potential	Flowing quantity	Flow	(units)
Electrical	Voltage	Positive charge	Current	(A)
Fluid	Pressure	Fluid	Flow rate	(m^3/s)
Thermal	Temperature	Heat	Heat flux	(W)

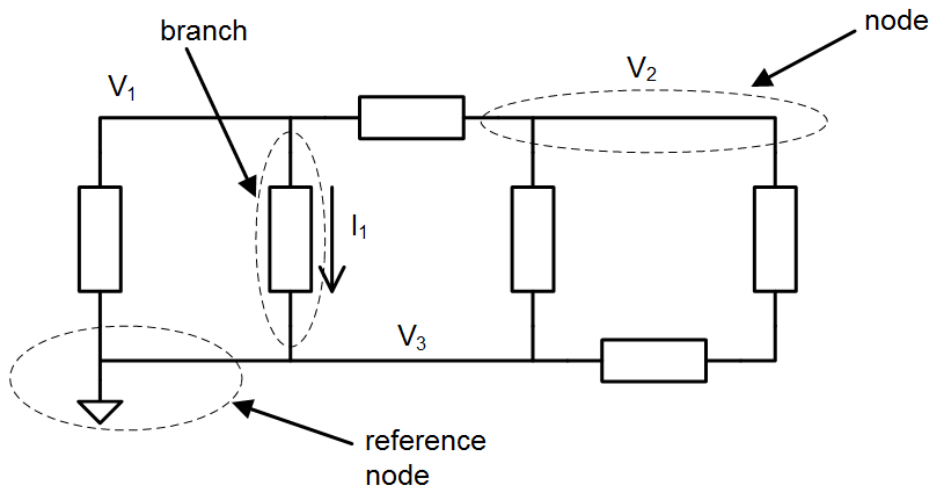# Electrical Circuits

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Electrical Networks – Schematics

□ Electrical circuits represented graphically with *schematics*

- ◘ Schematic symbols represent circuit elements
- ◘ Schematics detail connections between circuit elements
- ◘ Schematics describe paths for the flow of electrical current

□ Some examples:
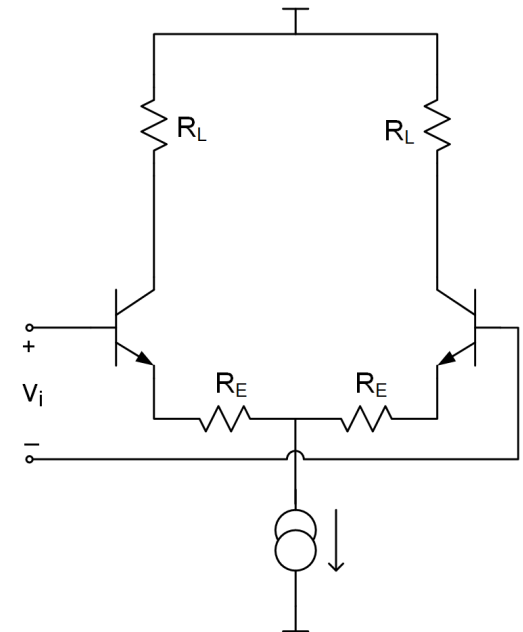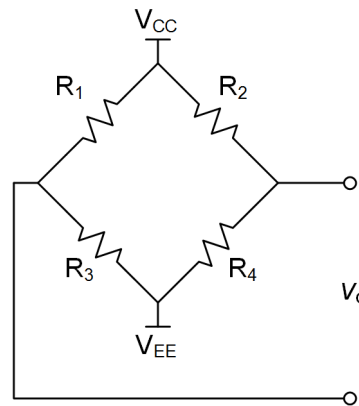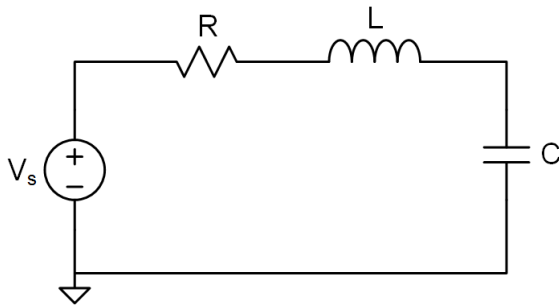
Electrical Networks – Branches & Nodes

- ☐ **Nodes**
  - ◘ Connection points for circuit elements
  - ◘ Node voltages given with respect to a reference node (0 V, ground)
    - ▪ E.g., $V_3 = 0$ V, here
  - ◘ Current flows into and out of nodes

- ☐ **Branches**
  - ◘ Paths for current to flow
  - ◘ Connections between nodes
  - ◘ Branches are the components that comprise the circuit
  - ◘ Voltage across a branch is the difference between node voltages at either end

Short Circuits & Open Circuits

- **_Short circuit_**
  - Direct connection between multiple nodes in a circuit
  - A direct path for current to flow
  - Often refers to an unintentional connection

- **_Open circuit_**
  - Lack of any electrical connection between two nodes in a circuit
  - No path for current to flow
  - Again, often used to refer to an unintended condition

open circuit

short circuit
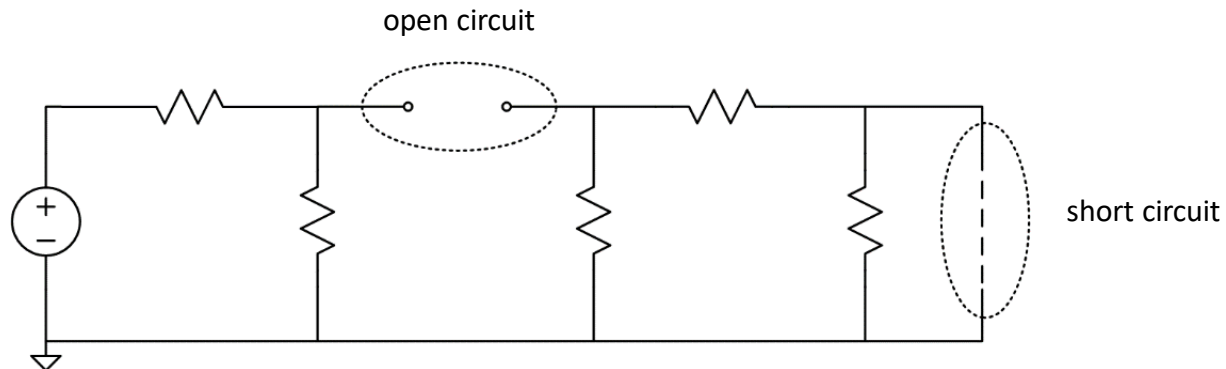
Complete Circuits

- Electrical current always flows in a ***complete circuit***
  - A return current path must always exist for current to flow
  - Consider a simple lamp:
    - Two-conductor cord – line and neutral
    - Current flows from socket, down one conductor – line
    - Current flows through the bulb
    - Current returns back along the neutral conductor to the wall, and, ultimately, to the power plant
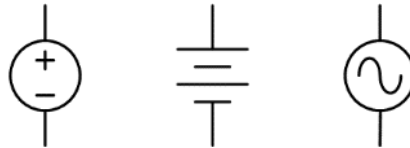 - Ladder on a power line vs. bird on power line

15 Electrical Circuit Components

Circuit Components

- *Voltage source*
  - **Schematic symbol:**
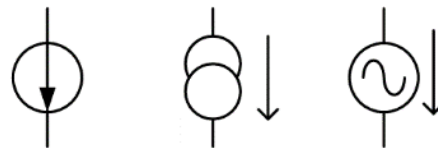

  - **Description:**
    - Generates a fixed voltage between its terminals
    - DC or AC
  - **Units**: volts (V)

- *Current source*
  - **Schematic symbol:**

  - **Description:**
    - Generates a fixed current
    - DC or AC
    - Current flows in one terminal and out the other
  - **Units**: amperes (A)

Circuit Components
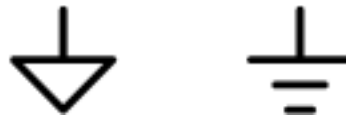
- *Resistor*
  - **Schematic symbol:**

  - **Description:**
    - Circuit element that resists the flow of electrical current
    - Intentional or parasitic resistance (even wires are resistive)
  - **Units**: ohms (Ω)

- *Ground*
  - **Schematic symbol:**

  - **Description:**
    - Voltage reference for a circuit
    - Ground node
    - Potential of 0 V

Circuit Components

- *Capacitor*
  - **Schematic symbol:**

  - **Description:**
    - Stores energy in an electric field
    - Two electrodes separated by a dielectric
    - Stores a charge differential between the two electrodes
  - **Units**: farads (F)

- *Inductor*
  - **Schematic symbol:**

  - **Description:**
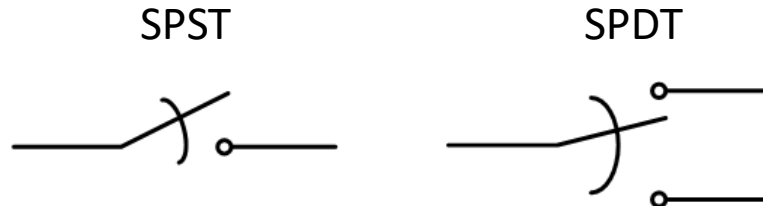   - Stores energy in a magnetic field
    - A coil of wire
  - **Units**: henries (H)

Circuit Components

□ *Switch*

    ▫ **Schematic symbol:**

SPST   SPDT

    ▫ **Description:**

- Controls connections between multiple nodes in a circuit
- Single-pole single-throw (SPST) switch makes/breaks connection between two nodes
- Single-pole double-throw (SPDT) switch connects one node to one of two other nodes
- Many other configurations, e.g. DPDT, 3PDT, 6P3T, etc.

Circuit Components

- ***Diode***
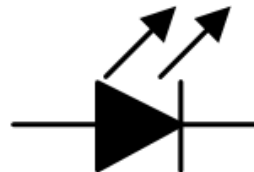 - **Schematic symbol:**

    anode ▶| cathode

  - **Description:**
    - Two-terminal semiconductor device
    - Junction of p-type and n-type semiconductor – a p-n junction
    - Allows current to flow in one direction only (anode to cathode)
    - Analogous to a check valve

- ***Light-emitting diode (LED)***
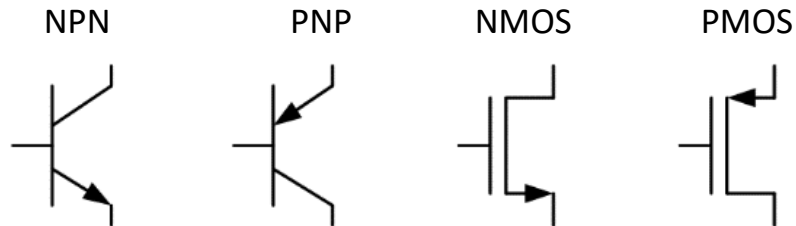 - **Schematic symbol:**

  - **Description:**
    - Diode that emits photons in response to current flowing through it

Circuit Components

- *Transistor*
  - **Schematic symbol:**

NPN   PNP   NMOS   PMOS

  - **Description:**
    - Three-terminal semiconductor device
    - Small voltage on/current into one terminal controls current flow between the other two terminals
    - Primary building block of integrated circuits
    - Can be used as *switches* or *amplifiers*
    - Analogous to *valves*:

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