Charg + Current

- The concept of electric charge is the underlying idea behind electric circuit analysis.

- Atoms consist primarily of neutrons, protons + electrons.
  - Electrons carry a negative charge
  - Protons carry a positive charge
  - Neutrons carry no charge

- Charge is measured in Coulombs (C)
  - Electrons carry a charge of \(-1.602 \times 10^{-19} \text{C}\)
  - Protons carry equal & opposite positive charge, thus atoms are electrically neutral

- Charge is neither created or destroyed
  - (Law of the conservation of charge)

- A Coulomb is a large amount of charge
  \(1 \text{C} = 6.24 \times 10^{18} \text{ electrons}\)
Charge & Current

- Electric charge can move.
  - In metallic conductors, electrons are the charge carrier.
- The movement of electric charge (electrons) constitutes electrical current.
- Electrical current exists when there is a net movement of electrons.

- "Electron Current" $\Rightarrow$ electrons moving
- "Conventional Current" $\Rightarrow$ positive charge moving (actually not true!)

![Diagram of conventional current and electron current flow](image)
- Electric current is the time rate of change of charge.
- Electric current is measured in Amperes (A), where
  \[ 1 \text{ A} = 1 \text{ C/} \text{sec} \]

  ![Diagram of current flow through a conductor]

  In 1 sec, \(6.24 \times 10^{18}\) electrons cross the plane surface.

- Mathematically, \( i = \frac{\Delta q}{\Delta t} \) (change in charge per unit time)

- **If current** constant with time, it is called *Direct Current* (DC)
- **If current** varies in time, it is called *Alternating Current* (AC)
**Change 1: Current**

- To describe current we must specify:
  - Magnitude, direction, a point of measurement (wire)

\[
4.7A \quad \rightarrow \quad \Leftrightarrow \quad -4.7A
\]

- To change the current arrow direction, multiply magnitude by -1
- To change the sign of the magnitude, flip the arrow direction

- Current is measured "through" something, not across
  - Ammeter measures current "in line"
  - Internally, ammeter appears as a short circuit to the circuit

![Current diagram]
Voltage.

- Charges in proximity to each other create an electric field.

- To push the charges apart, requires energy to be expended.

- This energy is provided by many possible sources:
  - Chemical (battery)
  - Mechanical (piezo element)
  - Thermal (peltier device)
  - Photonic (PV cell)

- The energy provided by the source separates positive and negative charges that give rise to a difference in potential energy.
Voltage is a measure of work required to separate charge, per unit charge.

Mathematically, \( V_{AB} = \frac{dW}{q} \) (Joules per Coulomb)

- 1 volt = \( \frac{1 \text{ Joule}}{1 \text{ Coulomb}} \)

"\( V_{AB} \)" also tells us that voltage is measured between two points.

To describe a voltage we need:
- 2 points, a magnitude, a reference terminal

- A point "a" is at a potential of \( V_{AB} \) volts higher than point "b".
- There is a voltage drop of \( V_{AB} \) from point "a" to point "b".

Voltage is measured across, current is measured through.
- Positive charge flows naturally from higher potentials to lower ones.
Voltage

- Voltage is relative to potential energy, thus it is a relative (between 2 points) not an absolute reference.

- Voltage is often measured with respect to a reference called "ground".
  
  ∙ ground symbol = $\downarrow$ or $\uparrow$

- If we do not specify what the other reference terminal is, then the reference is "ground" or another understood reference point.

- Gravitational potential analogy:

  ![Diagram showing gravitational potential with two points at different heights but same potential energy]
- Power is the time rate of expending or absorbing energy
  - Measured in watts (W)
  - \( P = \frac{\Delta W}{\Delta t} \) (Joules) / (seconds)

- \( P = \frac{dW}{dt} = \frac{dq}{dt} \) so \( P = V \cdot I \)
  - Instantaneous power

- Power absorbed or expended by a circuit element is the product of the voltage across the element and the current through the element.

- To compute power dissipated (absorbed) we must obey the Passive Sign Convention.
  - \( P_{\text{Ssupply}} \) current is entering the positive terminal of the element
  - If element is connected to obey \( P_{\text{Ssupply}} \), power dissipated (absorbed) is directly computed by \( P = V \cdot I \)
Power

\[ I = 2A \]
\[ V = 3V \]
\[ P = 2 \times 3 = 6W \]

Dissipating Power (as heat)

\[ I = -2 \]
\[ V = 8V \]
\[ P = (-2) \times 8 = -16W \]

Generating Power

\[ I = -4A \]
\[ V = -3V \]
\[ P = (-4) \times (-3) = 12W \]

Dissipating Power

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Power is dissipated when electrical energy is converted into another type of energy:

- Electrical → Heat (electric heater dissipates power)
- Energy → Light (light bulb dissipates power)
- → Torque (motor dissipates power)

Power is generated when another energy form is converted into electrical energy:

- Light (photons) applied to PV cell generates...
- Torque applied to generator generates...
- Heat applied to a thermo-electric cell generates...
Power

- In any circuit, the Algebraic sum of the power dissipated or generated by each element must be zero.

- Law of Conservation of Energy
  \[ \sum P = 0 \]
  
- Also, power generated = power dissipated

- Today, the concern is how much energy we consume, not how much power.
  
  - power is simply \( V \cdot I \)
  
  - energy consumed brings in the time dimension, i.e., for how long have we been consuming a given amount of power.
  
  \[ \text{energy} = \frac{V \cdot I \cdot t}{\text{watt} \cdot \text{hours}} \]

}
Circuit Elements

- Two types
  - Passive: can only dissipate power (resistors, transistors, ICs)
  - Active: can (but not necessarily) generate power

- A battery (active element) can be either
  - Discharged into a light bulb (generating power) (Active)
  - Be charged by a battery charger (dissipating power) (Passive)

- Independent Sources (Active)
  - Ideal voltage source

    ![Ideal Voltage Source Diagram]

    - Ideal voltage source sources whatever current necessary to maintain its terminal voltage

    - A large 12V (diesel or marine) battery approximates an ideal voltage source for currents to 10's of amps.
Circuit Elements

- Independent Sources (Active) [cont.]

  - Ideal current source

    ![Diagram of an ideal current source]

    - Ideal current source raises its terminal voltage to whatever voltage necessary to maintain its terminal voltage.

    - A constant speed motor driving a water pump is the closest analogy.
Circuit Elements

- Dependent Sources
  - These are sources that are controlled by an external voltage or current.
  - Diamond shape

- VCVS (Voltage Controlled Voltage Source)

- CCVS (Current Controlled Voltage Source)

- VCCS (Voltage Controlled Current Source)
  - (like MOSFET)

- CCCS (Current Controlled Current Source)
  - (like BJT)