Charge:

- In an atom, we have neutrons, protons and electrons.
  - Neutrons; do not carry any charge
  - Protons; positive charge
  - Electrons; negative charge
- Charge is denoted by `**q'** and is measured in Coulombs (abbreviated as **C**)
- 1 electron carries $-1.602 \text{ x } 10^{-19}$ C
- 1 C = sum of charges in $6.24 \text{ x } 10^{18}$ electrons
- Charge is quantized, that is, minimum possible value
- Conductors are materials with an abundance of *free* electrons
- Insulators have *no* free electrons
- Semi-conductors have *moderate number* of free electrons
- Like charges repel each other and opposite charges attract each other (Electrostatics)

Current:

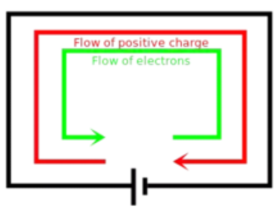
- Measures the rate of change in charge
- Denoted by *I*
- Unit: Ampere (Coulombs per second), abbreviated as **A**
- Mathematically; $I = I(t) = \frac{dq}{dt}$
- Formally, current results from charges in motion and 1A current corresponds to 1 Coulomb of charge moving across a fixed surface in 1 sec

<u>Current Direction:</u>

- The moving charges may be positive or negative.
- +ve charges (ions) movement produced +ve current. (Positive Charge Convention)

<u>More formally;</u>

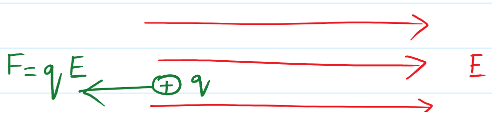
- The direction of an electric current is by convention the direction in which a positive charge would move.
- Electrons would actually move through the wires in the opposite direction.
- Thus, the current in the external circuit is directed away from the positive terminal and toward the negative terminal of the battery (depicted below)



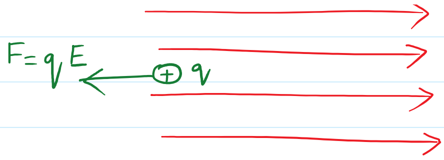
Voltage (Electric Potential or Electromotive Force):

<u>Work on Charges:</u>

- Use positive charge for easier explanation, always remember it has a negative charge somewhere
- An electric charge experiences a force in an electric field, which if unopposed, will accelerate the particle containing the charge
- Of interest here is the work done to move the charge against the field



* Moving charge against field makes it acquire potential energy



* Moving charge against field makes it acquire potential energy

- Electric potential or voltage is the difference in Electric Potential Energy per unit of charge between two points
- We define voltage as the amount of potential energy between two points.
- Another view point is that the voltage refers to the potential energy difference between two points that will impart one joule of energy per coulomb of charge that passes through it.
- Measured in Volts (abbreviated as *V*). Also called the potential difference or electromotive force
- Relationship to charge; Mathematically; $v = \frac{dW}{dq}$ $\quad (V = \frac{Nm}{C})$
- If 1 Joule of work is required to move 1 coulomb of charge from position 1 to position 2, then position 2 is at the potential of 1 Volt with respect to position 1

Power (Rate of change of work):

- $P = \frac{dW}{dt} = \frac{dW}{dq}\frac{dq}{dt}$ (using chain rule)
- $V = \frac{dW}{dq}$
- $I = \frac{dq}{dt}$
- $P = V \times I$ **(expanding of energy in time)**

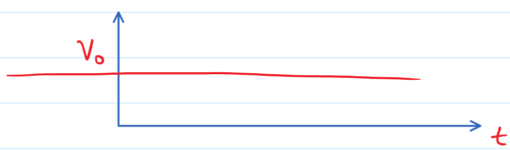
Energy:

- $W(t) = \int_{-\infty}^{t} P(\tau)\, d\tau$ (Joules)

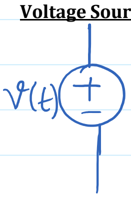
Summary so far;

- Charge, Current, Voltage, Power, Energy

Sources of Electrical Energy - Voltage and Current Sources:



Voltage Source

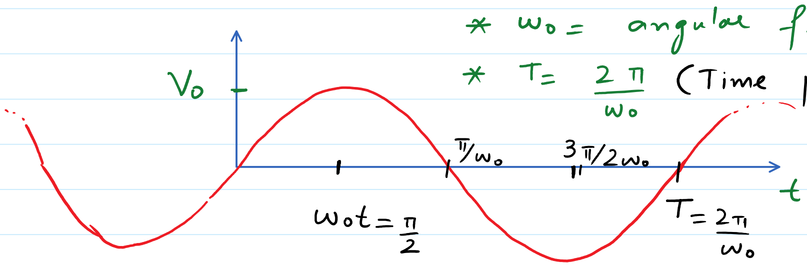


symbol.

* DC Voltage source ; $v(t) \equiv V = V_o$
* AC voltage source ;
  e.g.
  * $v(t) = V_o \sin w_o t$
    Sinusoidal voltage source

Examples
* Batteries
* Mains (AC)

* w_o = angular frequency
* $T = \frac{2\pi}{w_o}$ (Time period)



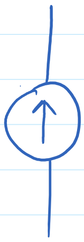
$\Rightarrow t = \frac{\pi}{2w_o} = \frac{T}{4}$

More common time-varying sources; saw-tooth, square, triangle

Current Source

Current Source

Symbol



$I(t) = I_0 \quad \forall t \quad (DC)$

$I(t) = I_0 \sin \omega_0 t \quad (AC)$

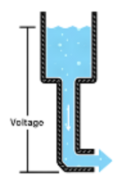
Examples

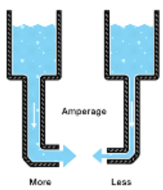
* Solar cells

Before we proceed further; let's try to understand basic concepts using water flow analogy and considering electric current a s water

Water Flow Analogy

- VOLTAGE - the pressure that pushes water through the hose.
- CURRENT - the flow of the water
- CHARGE - water
- RESISTANCE - hose-width





The pressure at the end of the hose can represent voltage
The water in the tank represents charge
The more water in the tank, the higher the charge, the more pressure is measured at the end of the hose
The higher the tank, the more pressure is measured

Width of the horse is inversely proportional to the resistance and directly proportional to the flow of the water
In other words, flow is directly proportional to pressure and inversely proportional to the width of the hose.

Circuit

- Closed loop that carries electric current. To be very precise, circuit is a path through which the current flows.
- Open circuit; If flow is disrupted
- Closed circuit; current is flowing in a path
- It is the interconnection of sources of electrical energy and other electrical components like Resistor, Capacitor and Inductor (at least for this course).

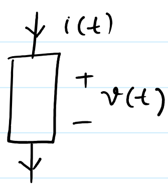
Passive and Active Elements

We use ***Passive Sign Convention*** to categorize basic electrical elements or components.

Passive Element (Component):
Element that dissipates energy.

Positive current enters positive terminal.

By passive sign convention, power dissipated by passive element is taken as positive.



* Component is dissipating energy

* power dissipated ; +ve $\quad v(t)\, i(t)$

* power supplied ; −ve

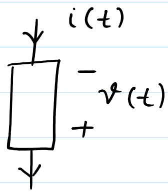
Active Element (Component):
Elements that supplies energy.

$\downarrow i(t)$

Active Element (Component):
Elements that supplies energy.

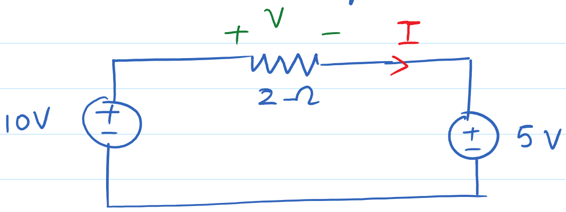
Positive current enters negative terminal.

By passive sign convention, power dissipated by an active element is taken as negative.
OR
By passive sign convention, power supplied by an active element is taken as positive.



Power dissipated ; −ve $-v(t)\,i(t)$
Power supplied ; +ve

Example (Although we have not yet studied resistor)

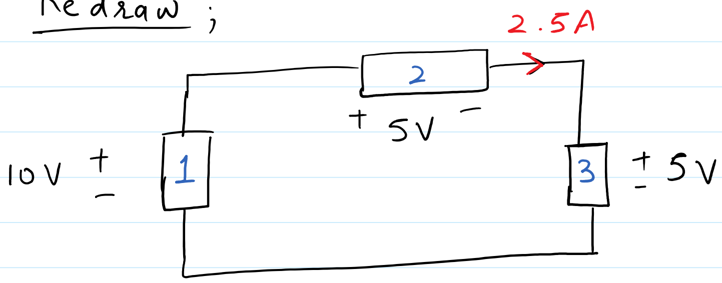


Using our prior knowledge

* $I = \frac{10-5}{2} = 2.5\,A$

* $V = (2.5)(2) = 5\,V$

Redraw ;

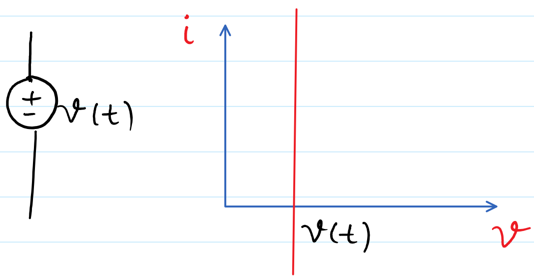


$P_1 = -25\,W$
$P_2 = 12.5\,W$
$P_3 = 12.5\,W$

ACTIVE ELEMENTS :-

* Voltage Source (Ideal)

- We characterize elements using current-voltage characteristics $(i - v)$

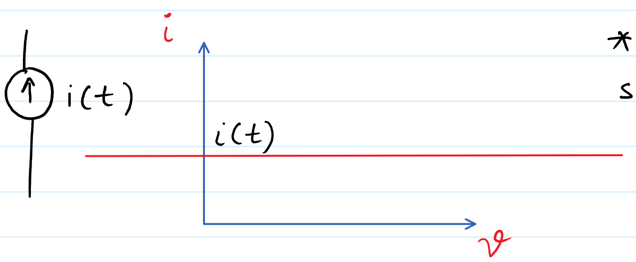


Interpretation:

* Voltage across terminals do not change irrespective of the current drawn from the voltage source.

* Note here that v(t) can be AC/DC

* Current Source (Ideal)



* Ideal current source always supply i(t) irrespective of the voltage across it.

ONE MORE OBSERVATION : $iv = p$ can be both +ve and −ve

=> sources can dissipate or supply energy

PASSIVE ELEMENTS :-

* Resistor ; Element defined by its property "Electrical Resistance".

* Resistance : A measure of difficulty offered by the material to the flow of electric current.

* Depends on the (i) nature of the material.
(ii) Shape of the material

Resistance, $R = \rho \dfrac{L}{A}$

Units $R \rightarrow \Omega$
$\rho \rightarrow \Omega\text{-}m$

$\rho \rightarrow$ Resistivity

Phenomenon : * Electrons moving through conductors scatter from atoms results in inelastic collision.

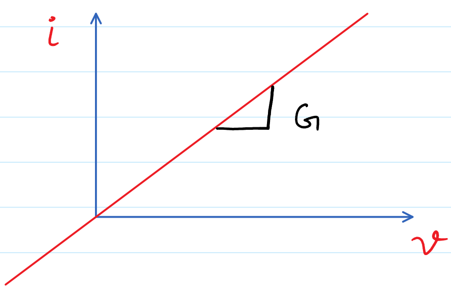
* Energy is lost as heat
* Amounts to loss in potential.

* Electrical Conductance : Inverse of Resistance

– denoted by $G = \dfrac{1}{R}$ (Units: Siemens (S))

– $G = \sigma \dfrac{A}{L}$ $\sigma = \dfrac{1}{\rho}$ → Conductivity (S/m)

I-V Characteristics :-



Slope of line ; G
Inverse of slope : $R = \dfrac{1}{G}$

* This relationship is governed by well-known Ohm's law ...

Ohms Law ; current through a conductor from one point to another is directly proportional to voltage across two points.

i.e., $I \propto V \Rightarrow I = GV \Rightarrow I = \frac{V}{R} \Rightarrow V = IR$

★ only true for two terminal linear-resistor

→ Straight-line IV characteristics

* Do we have a non-linear resistor? Diode

* Typical values of Resistances ; $1\,\Omega$ very small
$1\,M\Omega$ very large

* Examples ; 1 km overhead line ; $0.03\,\Omega$
Human body ; $1\,k\Omega \to 1\,M\Omega$

Power Dissipation in Resistors :-

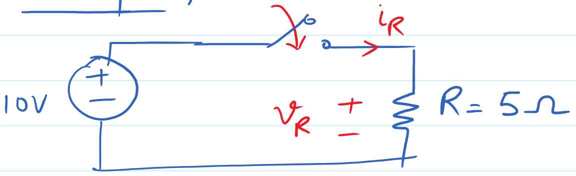
* Resistors always dissipate energy
  - see I-V characteristics (first and third quadrant)
  - ⇒ power always +ve (Dissipation)

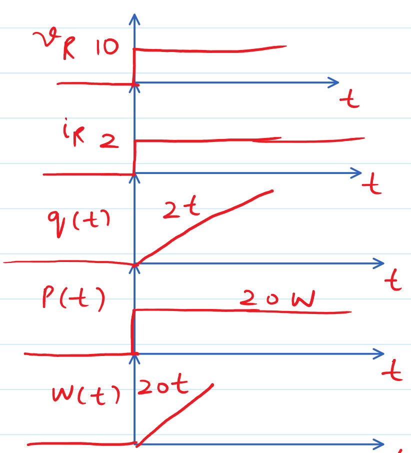
* $P = vi = I^2 R = \frac{V^2}{R}$

★ Energy is due to the fields ; not the charge
→ energy flows at the speed of light

$$W = \int_{-\infty}^{t} w(\tau)\, d\tau$$

Example ;





$$q(t) = \int_{-\infty}^{t} i(\tau)\, d\tau$$

$$= \begin{cases} 2t & t \geq 0 \\ 0 & t < 0 \end{cases}$$

$$w(t) = \int_{-\infty}^{t} p(\tau)\, d\tau = \begin{cases} 20t & t \geq 0 \\ 0 & t < 0 \end{cases}$$