Measurement & Units

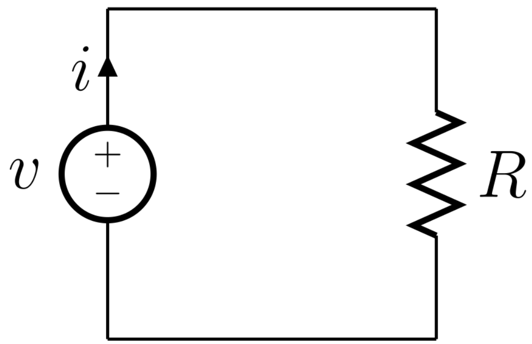
- Measurable quantity is defined by ‘number’ and ‘unit’.
- Example: 5 meters of wire; 6W lamp; 90 minute lecture
- Most frequent system of Units by National Bureau of Standards: International System of Units (SI units).
- The 7 basic units are given below.
- All other units are derived from these basic units. Eg. Unit of power is Watts (W). 1W= 1 kg m^2 s^{-3}

Base Quantity	Name	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

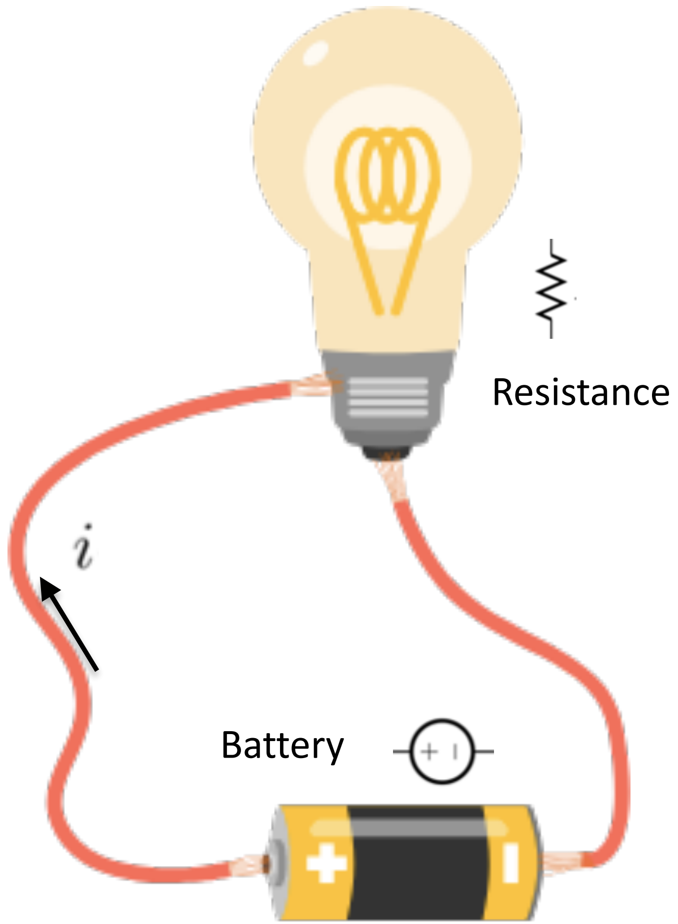
Basic SI units. Other units are derived from these.

Current

- Current is represented as *I*
- *Units: Amperes (Amps or A)*
- Current flows when battery is connected.
- The loop should be closed (ON)



- Current has a direction is always marked.
- What is meant by current flow? What flows?

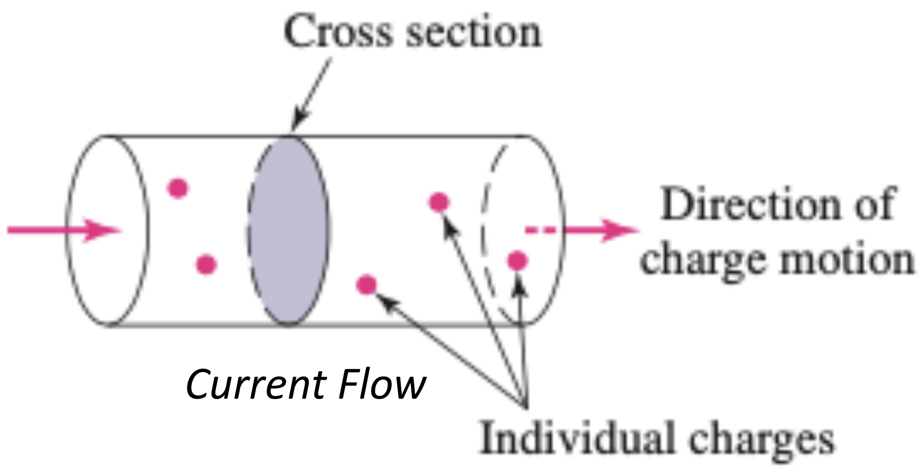


Current Flow

Ref: https://brilliant.org/discussions/thread/mit-graduates-struggle-to-light-a-bulb-with-a/

Charge

- Fundamental unit of 'electricity'
- Two types of charge:
  positive and negative charge
- Unit: Coulomb
- Motion of charge is current.



- 1 Coulomb = total charge that passes in 1 second through a cross section when 1 Ampere current flows
- Charge on 1 electron = - 1.602×10^{-19} C
- Charge on 1 proton = + 1.602×10^{-19} C
- Symbol: Q (constant with time), q (variable with time)
- Direction of current flow is direction of motion of positive charge.

Charge and Current

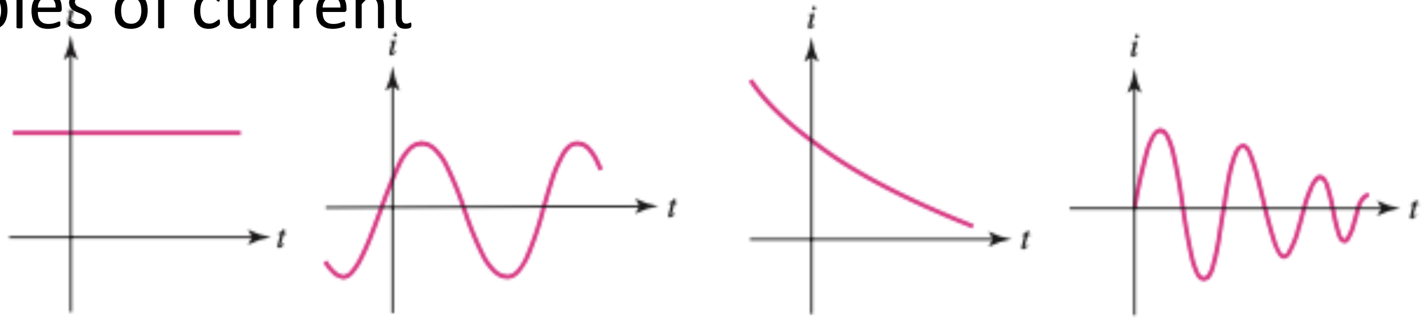
- General: If charge dq flows in dt time from a cross section of the wire, the wire is said to carry i current given by

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

- Alternatively,

$$\int_{q(t_0)}^{q(t)} dq = \int_{t_0}^{t} i \, dt'$$

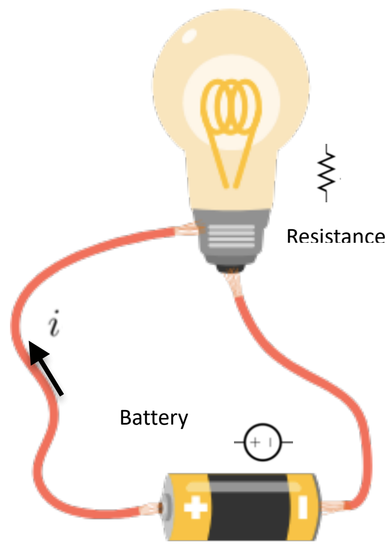
- Examples of current



Constant Current | Sinusoidal Current | Exponentially Decaying Current | Sinusoidal Decaying Current

Voltage

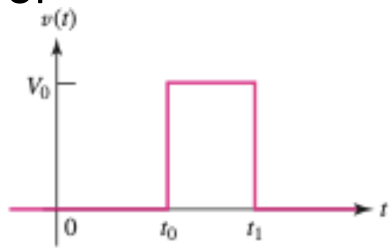
- Voltage (or *potential difference*) across a terminal of an element is a measure of work required to move 1C through the element.
- Units: Volts (V)
- 1 V=1 Joule/C
- Battery has energy stored. when a circuit/ closed loop is made, the energy is expended by moving the charges.



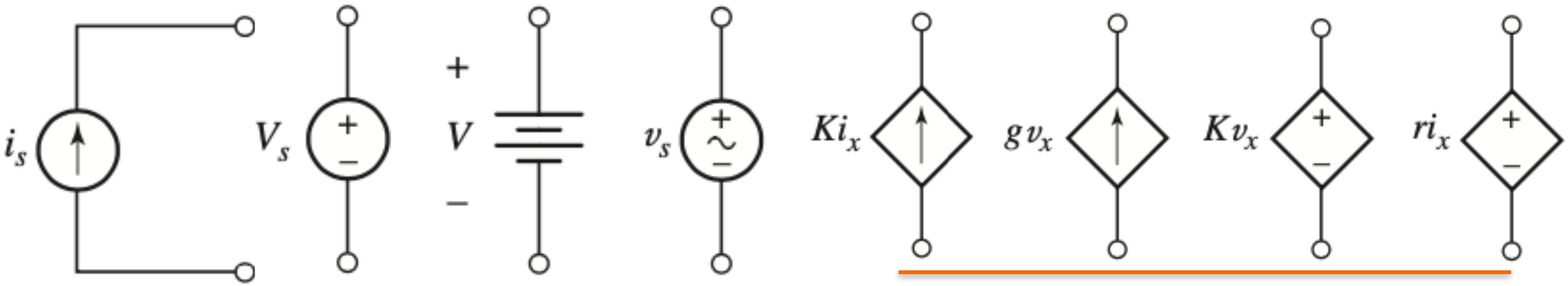
Voltage (potential difference) causes charge flow.

Sources or Circuit inputs stimuli

- Ideally we can input circuit with any voltage (or current depending on the circuit).
- The input can be constant (time independent) or vary with time (e.g. sinusoidal or square wave, impulse).
- Sources can be **independent** or **dependent**
- Independent sources do not depend on any other parameter (i or v)
- Dependent sources provide output which is a function of another current or voltage

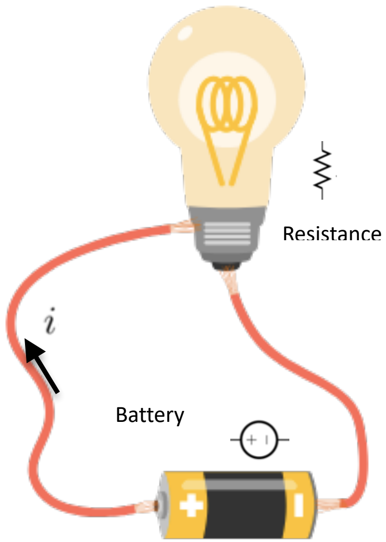


Impulse Input

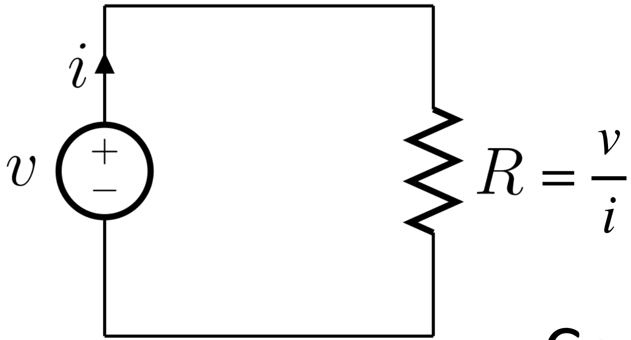


Current Source *Voltage Sources* *AC Voltage Source Sinusoid* *Dependent Voltage Source*

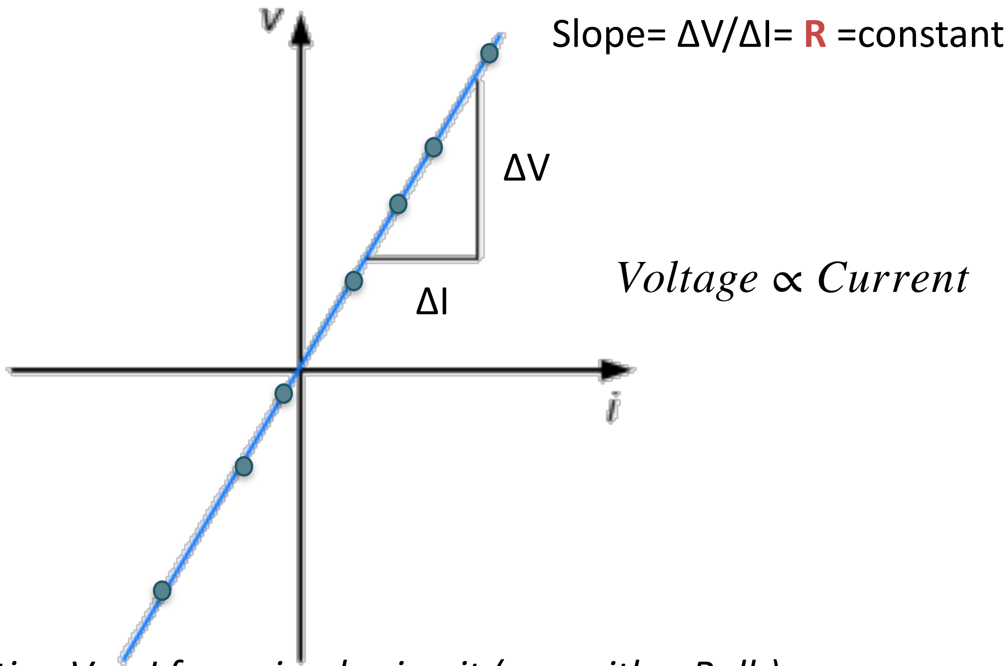
Current : how can we control the current



- Voltage is responsible for current flow.
- Higher voltage should result in a higher current flow.



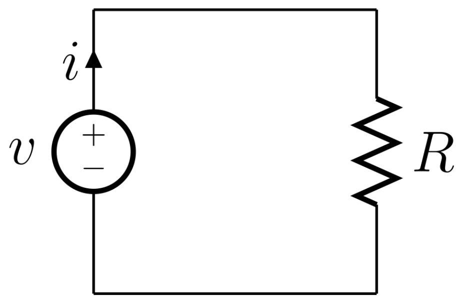
Equivalent Circuit



Plotting V vs I for a simple circuit (e.g. with a Bulb)

- Constant slope indicates constant Resistance

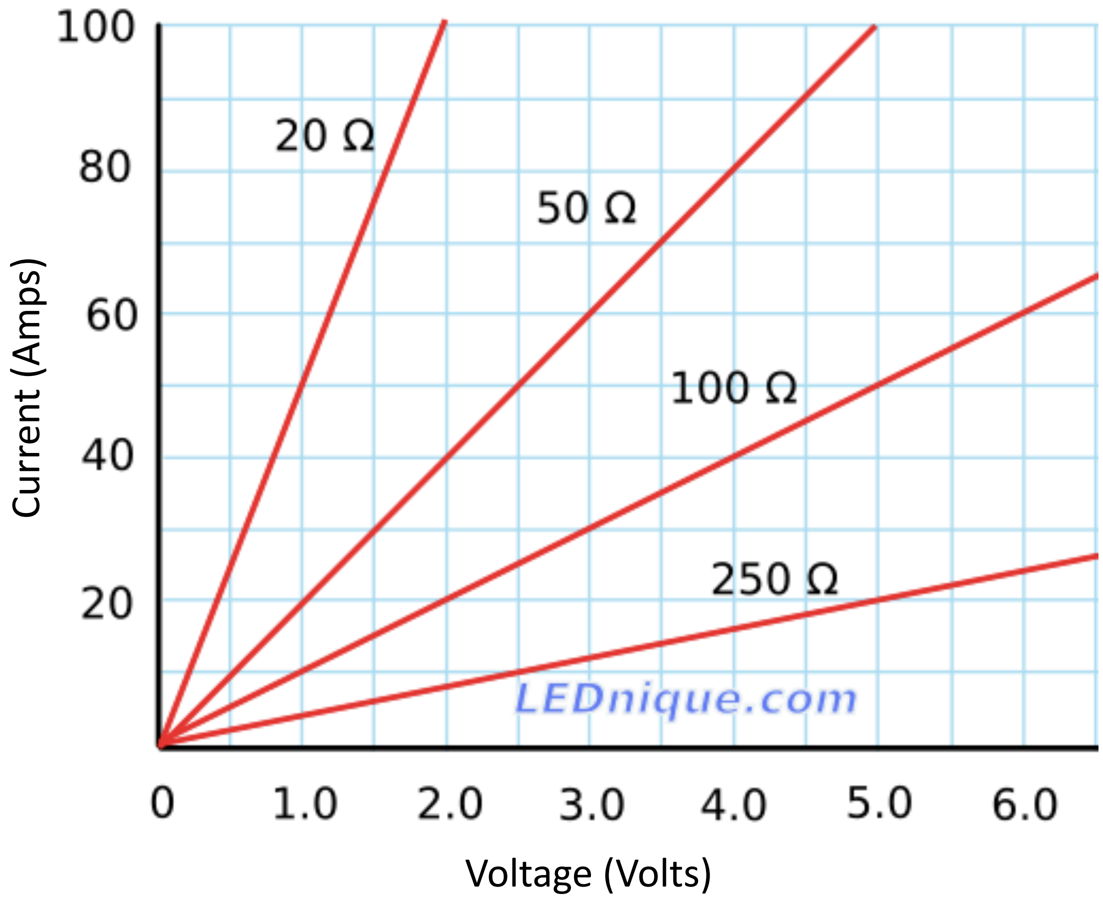
Resistance



- Changing the value of R gives gives us similar plots but with different slopes.
- It denotes the hinderance provided by the element.
- Units Ohm (Ω = Volts/Amps)

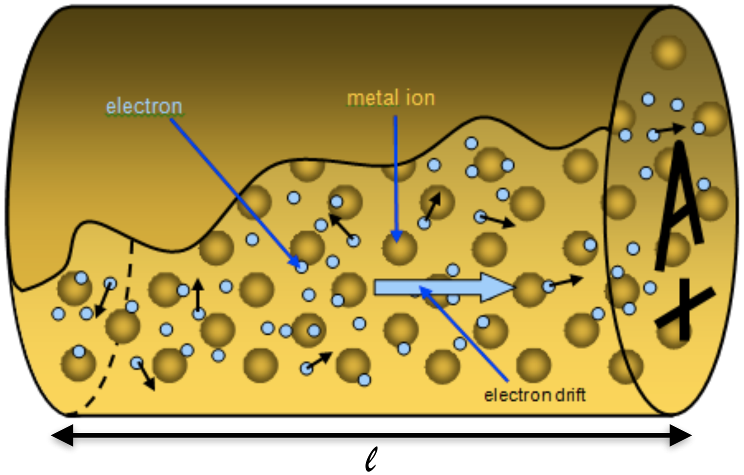
R =ΔV/ΔI= **R**

$$v = Ri$$ **Ohm's Law**



Plotting V vs I for a simple circuit (e.g. with a Bulb)

Resistance



Current flow in conductor

Resistance as a function of wire dimension

$$R = \rho \frac{\ell}{A}.$$

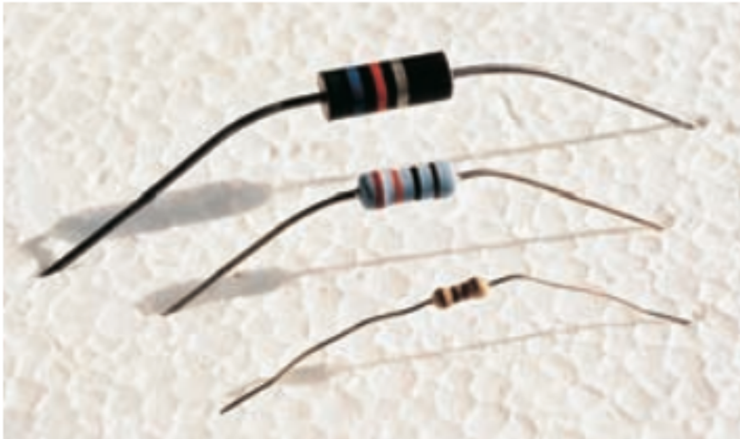
ℓ is the wire length
ρ is the resistivity of material
A is area of cross section

Conductance G is inverses of resistance 1/R.

Conductivity is inverse if resistivity

$$\sigma = \frac{1}{\rho}.$$

- Resistance is provided to charge (electron) flow in the conductor.
- Higher the resistance, lower is the current.
- Resistance is the property of the material.
- Copper, aluminium, silver provide lower resistance to current flow (they have higher conductance).



Resistor packages available commercially

https://www.schoolphysics.co.uk/age16-19/Electricity%20and%20magnetism/Current%20electricity/text/Free_electron_motion/index.html

Ohms Law

- **Ohm's law** states that the voltage across conducting material is directly proportional to the current.

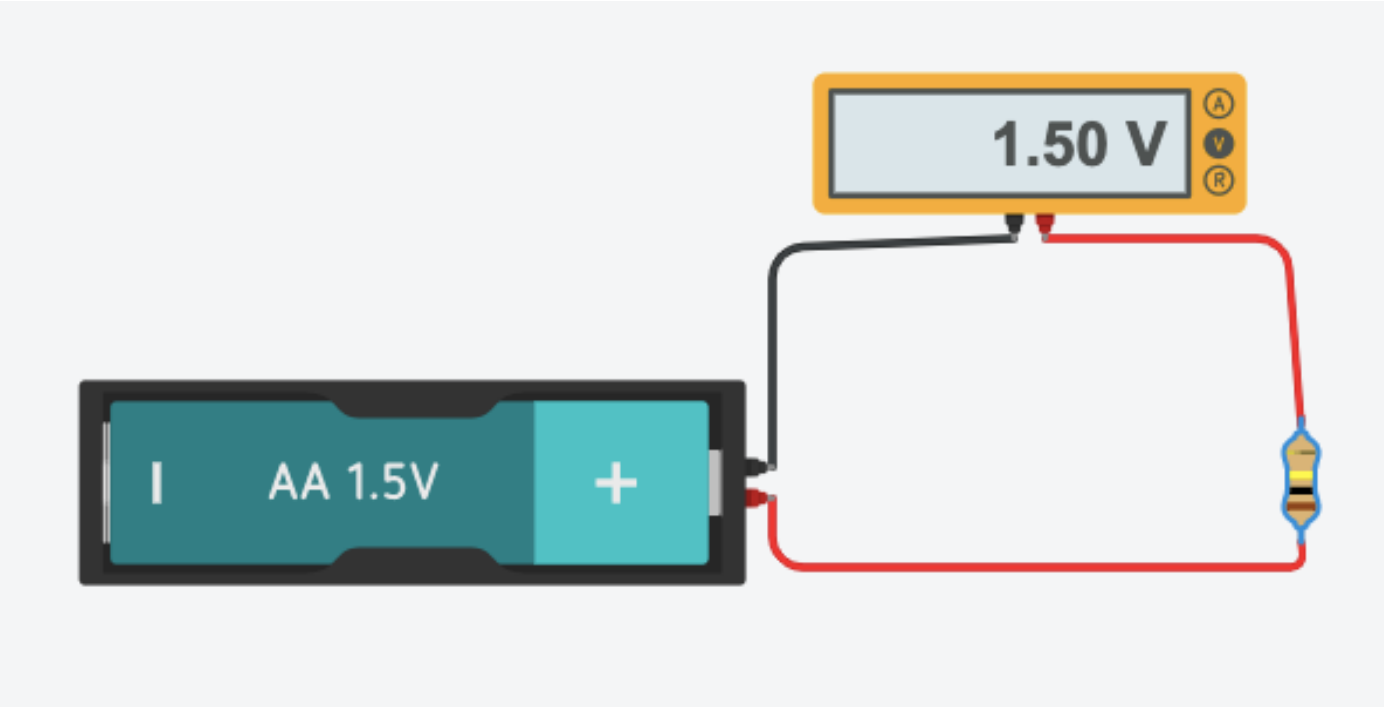
$$Voltage \propto Current \Rightarrow \quad v = Ri$$ Ohm's Law

- The constant of proportionality is called the **Resistance**

$$R = \frac{V}{I}$$

- Resistance of any circuit can be calculated by measuring voltage V & current I

Ohms Law: Demo



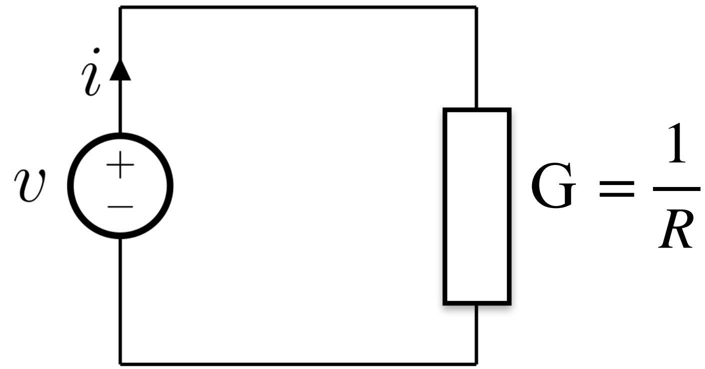
Power

- Rate of work done is defined as **Power.**
- Units: Watts (W = Joule/sec)
- If 1 Joule of energy is expended in transferring 1 Coulomb of charge through the device in 1 second, then the rate of energy transfer is 1 Watt.

$$p = vi$$

- Positive power is power spent. Negative power is power supplied (or generated).
- Alternate expression for power $p = vi = i^2R = v^2/R$

Conductance



- Reciprocal of resistance is conductance.
- G is symbol conductance.
- Unit: Siemens (S = 1 A/V) or mho ℧
- *Ohm's Law* $\frac{i}{v} = \frac{1}{R} = G$ *Power* $p = vi = v^2 G = \frac{i^2}{G}$

Example: Resistance & Power

The 560 resistor is connected (in series) to a circuit which causes a current of 42.4 mA to flow through it. Calculate the voltage across the resistor and the power it is dissipating.

<u>Solution</u>:

$\mathrm{v} = Ri = (560)(0.0424) = 23.7\ \mathrm{V}$

$p = \mathrm{v}i = (23.7)(0.0424) = 1.0\ \mathrm{W}$

$p = \mathrm{v}^2/R = (23.7)^2/560 = 1.0\ \mathrm{W}$

$p = i^2 R = (0.0424)^2(560) = 1.0\ \mathrm{W}$

Example: Resistance & Power

A dc power link is to be made between two islands separated by a distance of 24 miles. The operating voltage is 500 kV and the system capacity is 600 MW. Calculate the maximum dc current flow, and estimate the resistivity of the cable, assuming a diameter of 2.5 cm and a solid (not stranded) wire.

<u>Solution</u>:

Maximum current $= \dfrac{600 \times 10^6}{500 * 10^3} = 1200$ A

Rcable = 417 ohms

Wire cross sectional area 4.9 cm2

Resistivity =520 uohm.cm

Example: Conductance

Calculate the conductance of a specimen if a current of 50 mA flows in it when a voltage of 6 V is applied across it.

Solution:

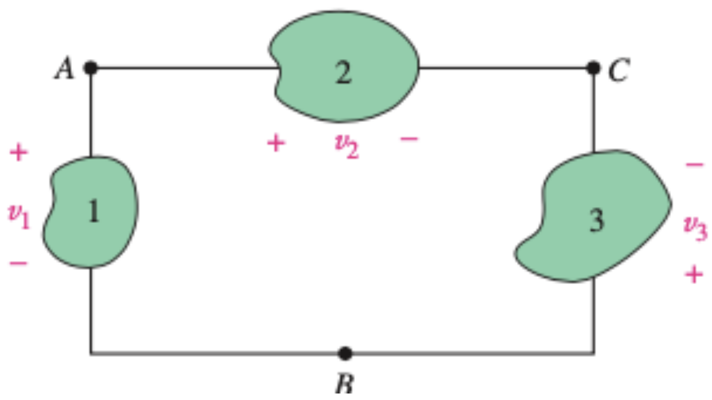
Conductance = I/V = 0.005/6 = 8.33×10^{-4} siemens = 12 millisiemens.

Reference point for Potential

- Potential (difference) or voltage is always measured with respect to a reference point.
- Mostly it is called as ground (lowest potential).
- Ground (GND) is taken to be V=0
- All other voltage points are measured w.r.t GND
- Any other point can be taken as reference. This will not affect the current or resistance (or any impedance) values.

Loop Voltage: KVL Kirchhoff's Voltage Law

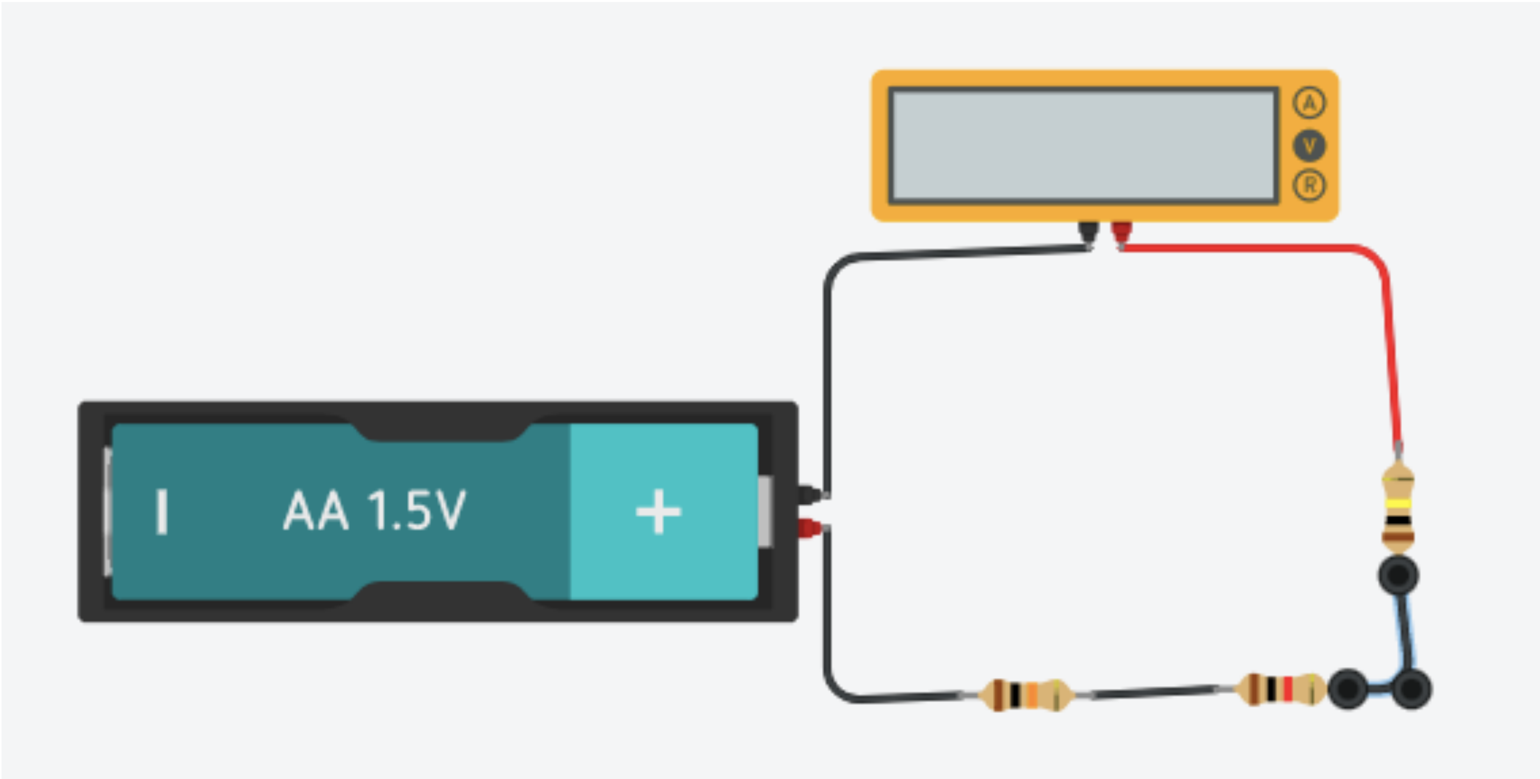
- Kirchhoff's Voltage Law
  - Sum of all voltages along any closed path is zero.



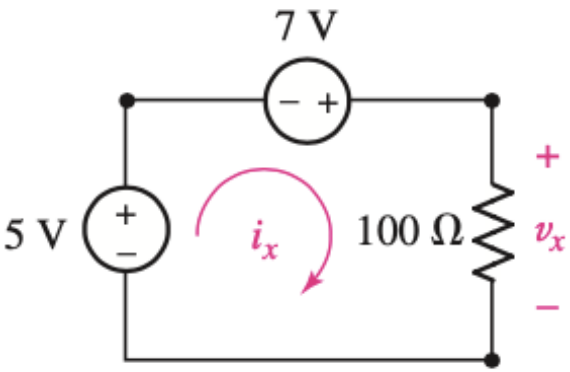
$$v_1 + v_2 + v_3 + \cdots + v_N = 0$$

$$\sum_{n=1}^{N} v_n = 0$$

KVL Demo

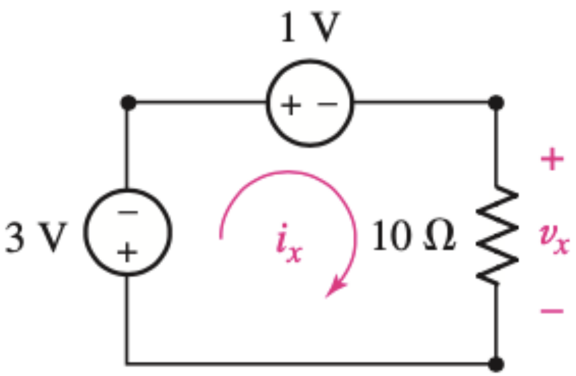


KVL Examples

- 

$$-5-7+v_x=0$$

$$i_x = \frac{v_x}{100} = \frac{12}{100} = 120mA$$



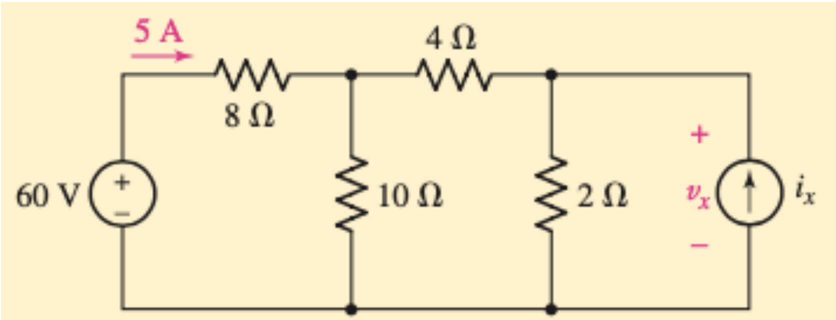
$-3-1-v_x=0$

$-4=10\ i_x$

$v_x=-4V;$

$i_x=-400mA.$

KVL Examples

- 

Solve for v_x

Loop1: $60-8*5-10*(5-I_2)=0$

Loop2: $10*(I_2-5)-4*I_2-2*(I_2-I_3)=0$

Loop3: $2*(I_3-I_2)-v_x=0$

And $I_3=-i_x$

Solve for unknowns: I_2, I_3, v_x

Answers:

$I_2 = 3A$

$I_3 = 19A$

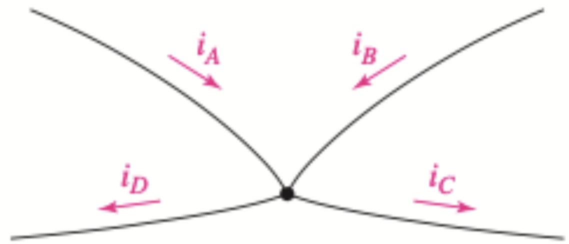
$V_x = 32$ V

River confluence

Loop Currents: KCL Kirchhoff's Current Law

- Algebraic sum of all currents entering (or leaving) a node (junction) in a circuit is zero.

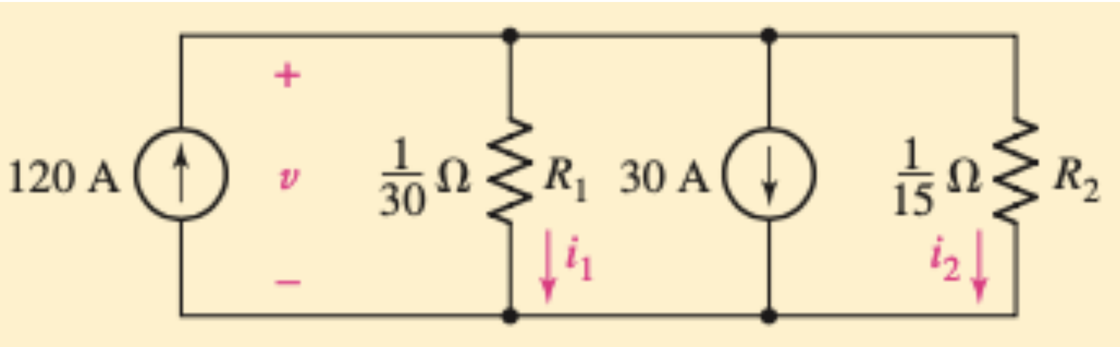
$$i_A + i_B + (-i_C) + (-i_D) = 0$$



$$i_A + i_B = i_C + i_D$$

KCL Example

- Analyse & find the voltage & currents



- Solution

$$120 - \frac{v}{R1} - 30 - \frac{v}{R2} = 0$$

$$120 - \frac{v}{1/30} - 30 - \frac{v}{1/15} = 0$$

- $v = 2\text{V}$
- $i_1 = 60A$
- $i_2 = 30A$

KCL Example

- Which of these circuit is valid