UNIT-1
Fundamentals of D.C. circuits

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- ✓ Work, Power, Energy
- ✓ Ohm's Law
- ✓ Resistance(Series and Parallel)
- ✓ Inductor (Series and Parallel)
- ✓ Capacitor (Series and Parallel)

Electrical Circuit

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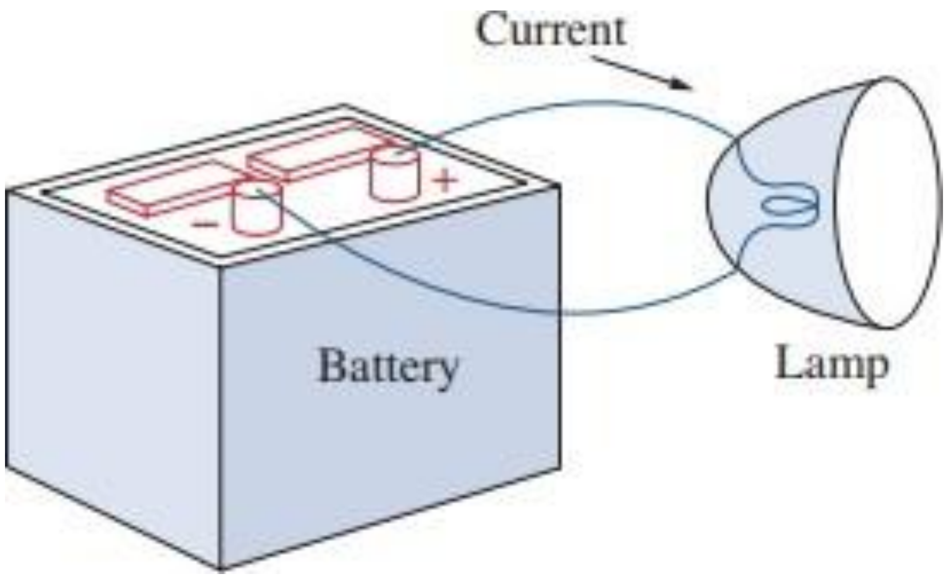
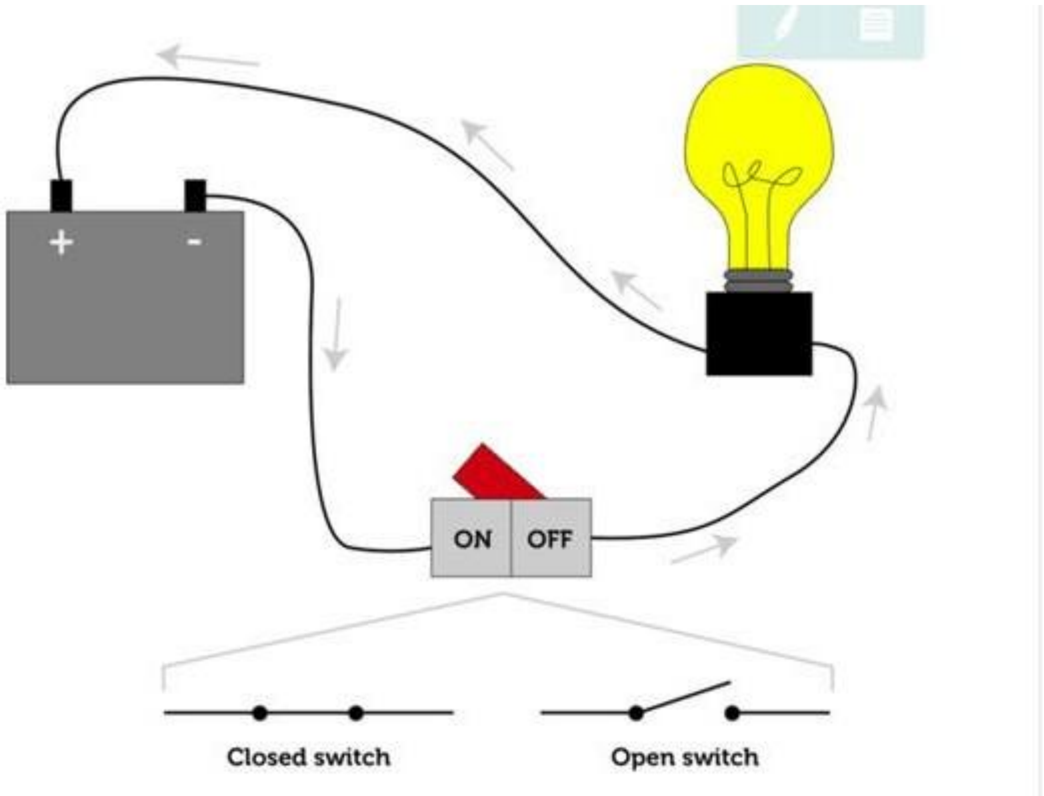




Charge and Current

- **Charge:** Charge is an electrical property of the atomic particles of a matter.

  S.I Unit: Coulomb (C)

  Symbol: Q

- **Current:** Rate of change of charge.

  OR

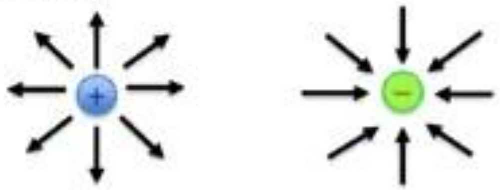
  Continuous flow of electrons in an electrical circuit.

  S.I Unit: Ampere (A)

  Symbol: I

Why does electric charge flow?

- Charged particles exert a force on other charged particles.
- This force per unit charge is called an electric field.
- The electric field points away from a positive charge and towards a negative charge



- Therefore, charges flow because their electric fields exert forces that push each other.

ELECTRIC CURRENT

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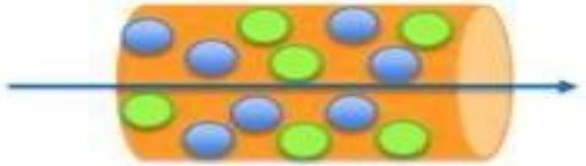
Define electric current

- Electric current (I) is the quantity of charge (Q) that passes through a given area in a specified time (t).



- The current as a function of time is

$$i(t) = \frac{dQ(t)}{dt}$$

- For constant current,

$$I = \frac{Q}{t}$$

- Variable: i, I

$$Units : \frac{C}{s}, Amperes$$

Charge and Current

- Mathematically,

$$I = \frac{dQ}{dt}$$

Or, in simple terms:

$$I = \frac{Q}{T}$$

So, 1 Ampere = 1 coulomb/ 1 second.

Quiz

1 mm of cross section of copper wire is isolated and 50 C of charge flows through it for 2 seconds. How much current will flow through wire?

A. 50

B. 100

C. 25

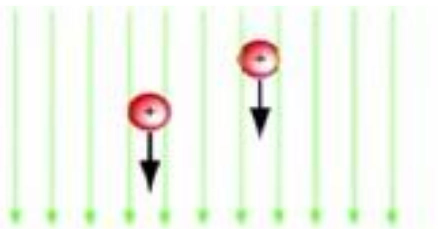
D. 0.04

QUIZ

1 mm of cross section of copper wire is isolated. The charge that flows in the cross section is
$Q(t) = 4t^2 + 5$, How much current will flow through wire in 6 seconds.

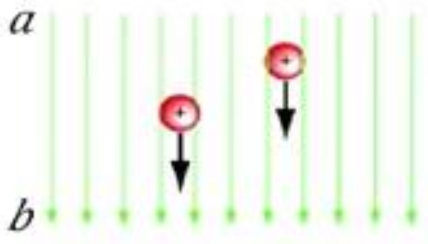
A. 149 A
B. 48 A
C. 53
D. 5A

Voltage



- When moving through an electric field, a charge either gains energy or loses energy.
- Charge loses energy when moving in the same direction of the electric field lines.
- Charge gains energy when moving in the opposite direction of electric field lines.
- Voltage is the energy either gained or lost per coulomb of charge.

How do you calculate voltage?



- Voltage (V) is the change in energy (w) per coulomb of charge (C)

$$V = \frac{dw}{dq}$$

- Or voltage can be expressed as energy in joules (J) over charge in coulombs (C)

$$V = \frac{energy}{charge}$$

- Variable: V

$Units: \frac{J}{C}, volts$

Power and Energy

- Power: Rate at which the work is done.

OR

Time rate of absorbing or supplying energy

S.I Unit: Watts (W)

Symbol: P

Mathematically,

$$P = \frac{dW}{dt} = \frac{dW}{dq} \cdot \frac{dq}{dt} = V.I$$

Implies, $\boxed{P = V.I}$

QUICK QUIZ (Poll)

1 Coulomb is same as:

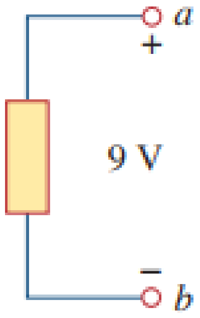
A. Watt /sec
B. Ampere/sec
C. Joule-sec
D. Ampere-sec

Voltage

- It is the energy (Work) required to move a unit charge through an element.

  S.I Unit: Volt (V)

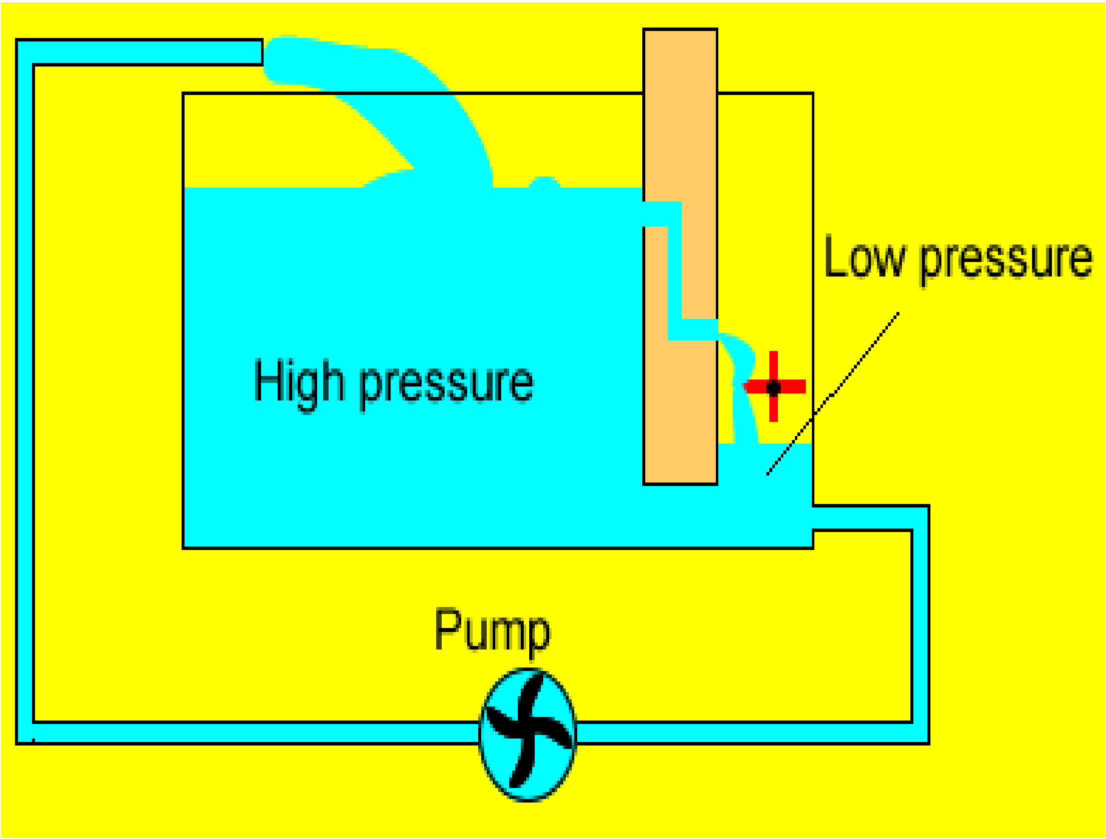
  Symbol: V



(a)

$$v_{ab} = -v_{ba}$$

$$1 \text{ volt} = 1 \text{ joule/coulomb}$$



Power and Energy

- **Energy:** Capacity of doing work.

  S.I Unit: Joules(J)

  Symbol: E

QUICK QUIZ (Poll 3)

Calculate the current ratings of 100 Watt incandescent bulb and 15 Watt LED lamp operated with the domestic supply of 220 Volt?

A. Bulb = 0.068 A and LED = 0.45 A

B. Bulb = 0.45 A and LED = 0.068 A

C. Bulb =0.50 A and LED = 0.068 A

D. Bulb = 0.50 and LED = 0.68 A

Network Components

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Active

Battery

Transistor, Op-amp, etc

Passive

Resistance (R)
Capacitance (C)
Inductance (L)

QUICK QUIZ (Poll 5)

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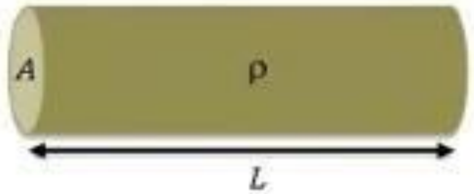
Identify the passive element

A. Battery
B. Transformer
C. Transistor
D. OP-amp
E. None of these

Resistance

Resistance and Resistivity



$$\rho_{metals} = 10^{-8} \; to \; 10^{-3} \; \Omega m$$
$$\rho_{rubber} = 10^{5} \; to \; 10^{15} \; \Omega m$$

- When charged particles flow through a material, they encounter electrical resistance (R).
- Electrical resistance is determined by the material's cross sectional area (A), length (L), and resistivity (ρ).
- The resistivity is an intrinsic property that quantifies the material's opposition to charge flow.
- Variable: R
- Unit: $\frac{V}{A}, \Omega, ohms$

- $R = \frac{\rho L}{A}$

Resistance

- Resistance: It is an opposition to the flow of current.

  S.I Unit: Ohm (Ω)

  Symbol: R

Capacitance

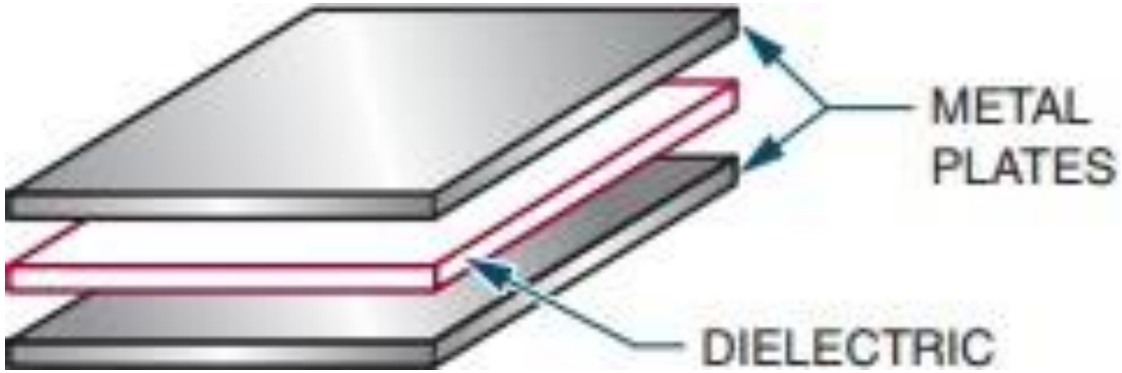
- Capacitance is the ability of a device to store electrical energy in an electrostatic field.
- A capacitor is a device that stores energy in the form of an electrical field..
- A capacitor is made of two conductors separated by a dielectric.

S.I Unit: Farad (F)

Symbol: C

Two important Properties:

1. No current flows through the capacitor, if the voltage remains constant.
2. Voltage across a capacitor cannot change instantaneously.



Inductance

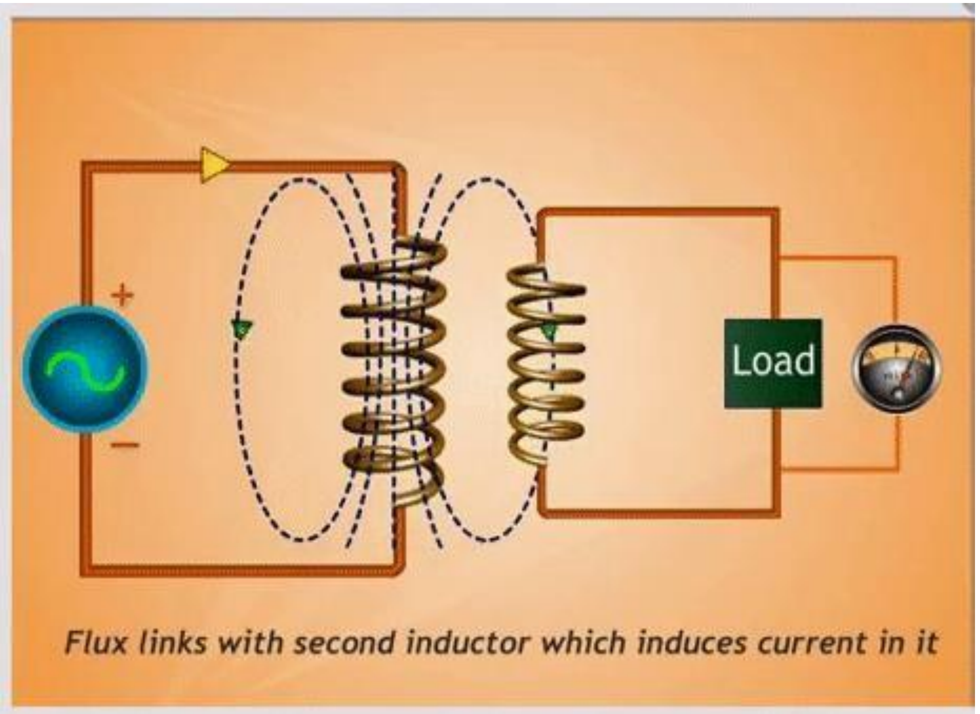
- Inductance is the characteristic of an electrical conductor that opposes a change in current flow.
- An inductor is a device that stores energy in a magnetic field.
- When a current flows through a conductor, magnetic field builds up around the conductor. This field contains energy and is the foundation for inductance

S.I Unit: Henry (H)

Symbol: L

Two important Properties:

1. No voltage appears across an inductor, if the current through it remains constant.
2. The current through an inductor cannot change instantaneously.



Ohm’s Law

- Ohm’s law states that:

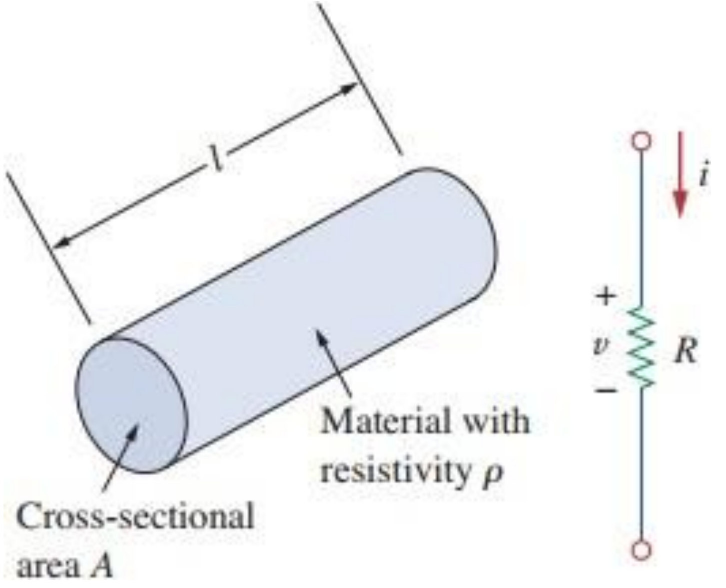
“the current in an electric circuit is directly proportional to the voltage across its terminals, provided that the physical parameters like temperature, etc. remain constant”

Mathematically,

$$I \propto V$$

Or,

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



Resistivity Table

Material	Resistivity ($\Omega \cdot m$)	Usage
Silver	1.64×10^{-8}	Conductor
Copper	1.72×10^{-8}	Conductor
Aluminum	2.8×10^{-8}	Conductor
Gold	2.45×10^{-8}	Conductor
Carbon	4×10^{-5}	Semiconductor
Germanium	47×10^{-2}	Semiconductor
Silicon	6.4×10^{2}	Semiconductor
Paper	10^{10}	Insulator
Mica	5×10^{11}	Insulator
Glass	10^{12}	Insulator
Teflon	3×10^{12}	Insulator

Conductance

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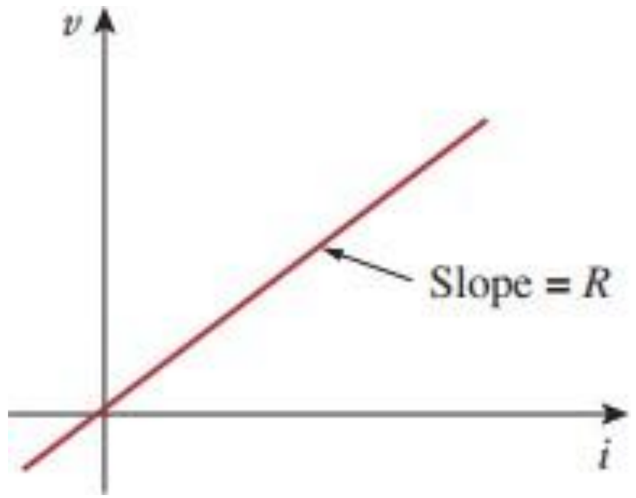
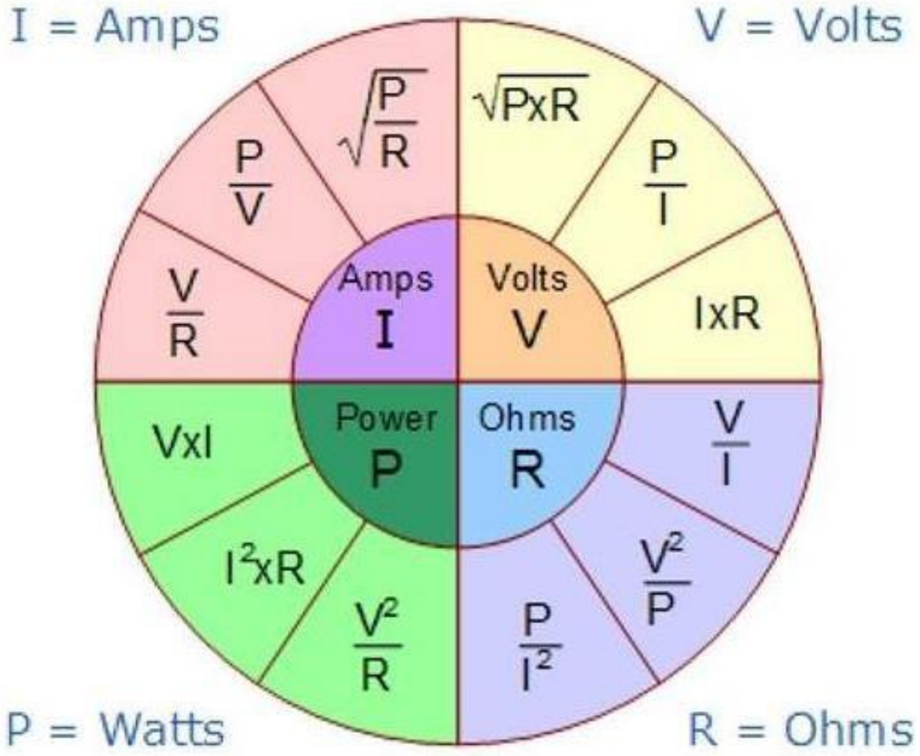
- A useful quantity in circuit analysis is the reciprocal of resistance R, known as conductance and denoted by G
- $G = \frac{1}{R} = \frac{I}{V}$
- S.I Unit: mho (ohm spelled backwards) or Siemens
- Symbol: ℧, the inverted omega.

$$1\ \mathrm{S} = 1\ \mho = 1\ \mathrm{A/V}$$

Interrelated terms

- Power dissipated in the resistor can be expressed as:
- $P = VI = I^2R = \frac{V^2}{R}$

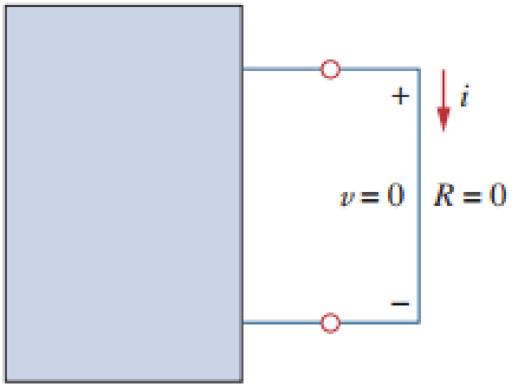




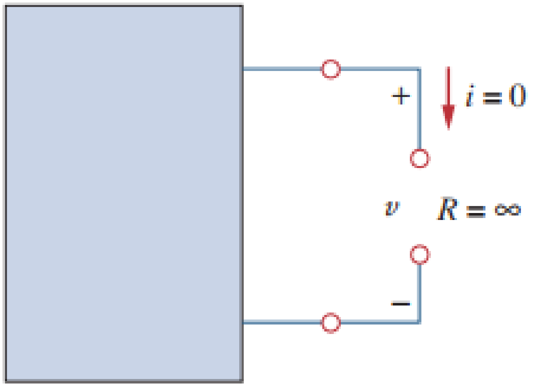
Ohm's Law Pie Chart (Source: Electronics-Tutorials.ws)

Short-circuit and Open-circuit

- For a short circuit, R = 0 Ω
- Therefore, V = I.R = 0 V
- NOTE: (current, I can be of any value)



- For an open circuit, R = ∞ Ω
- Therefore, I = V/R = 0 V
- NOTE: (voltage,V can be of any value)



Applications of Ohm's Law

1. To find unknown Voltage (V)
2. To Find unknown Resistance (R)
3. To Find unknown Current (I)
4. Can be used to find Unknown Conductance (G)=1/R
5. Can be used to find unknown Power (P)=VI
6. Can be used to find unknown conductivity or Resistivity

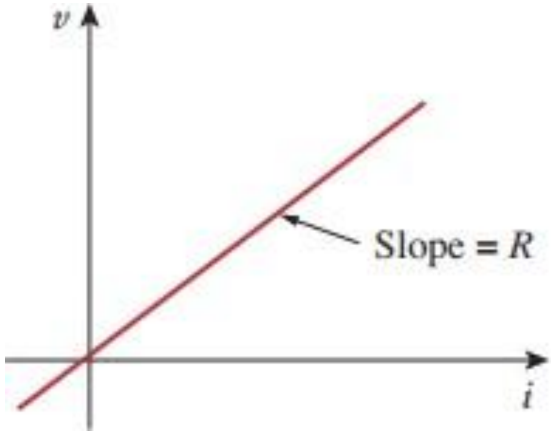
$\boxed{v = iR}$ $\boxed{R = \frac{v}{i}}$ **I=V/R** $R = \rho\frac{\ell}{A}$

Applications of Ohm's Law

1. It is widely used in circuit analysis.
2. It is used in ammeter, multimeter, etc.
3. It is used to design resistors.
4. It is used to get the desired circuit drop in circuit design (Example, Domestic Fan Regulator).
5. Advanced laws such as Kirchhoff's Norton's law, Thevenin's law are based on ohm's law.
6. Electric heaters, kettles and other types of equipment working principle follow ohm's law.
7. A laptop and mobile charger using DC power supply in operation and working principle of DC power supply depend on ohm's law.

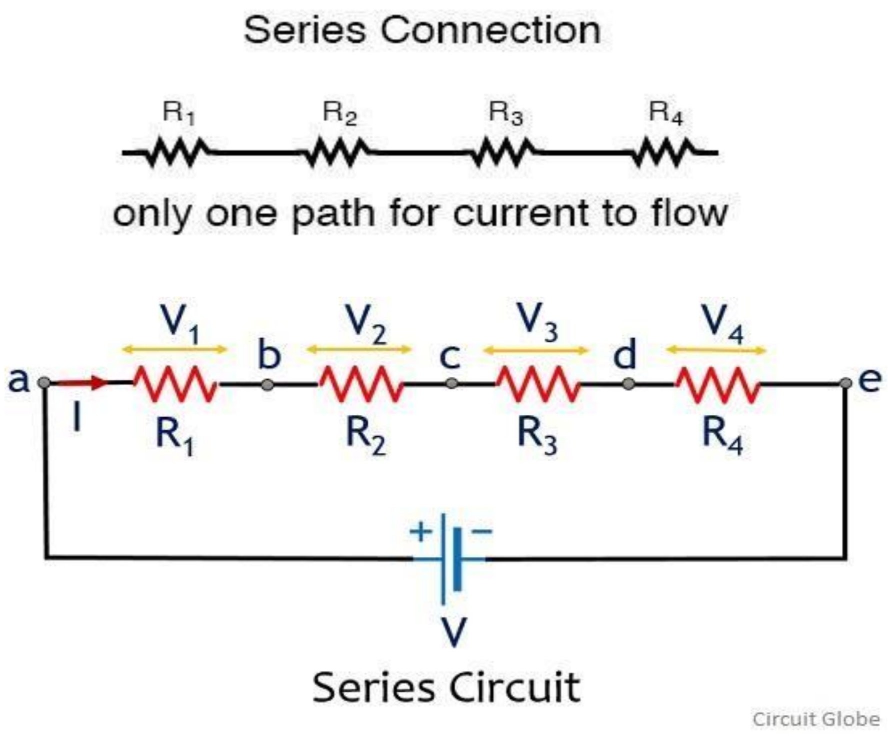
Limitations of Ohm’s Law

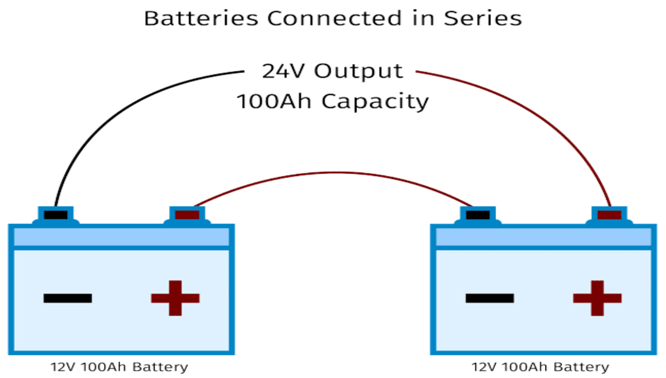
- Ohm’s law holds true only for a conductor at a constant temperature. Resistivity changes with temperature.
- Ohm’s law by itself is not sufficient to analyze circuits.
- It is NOT applicable to non linear elements, For example, Diodes, Transistors, Thyristors, etc.
- This law cannot be applied to unilateral networks.

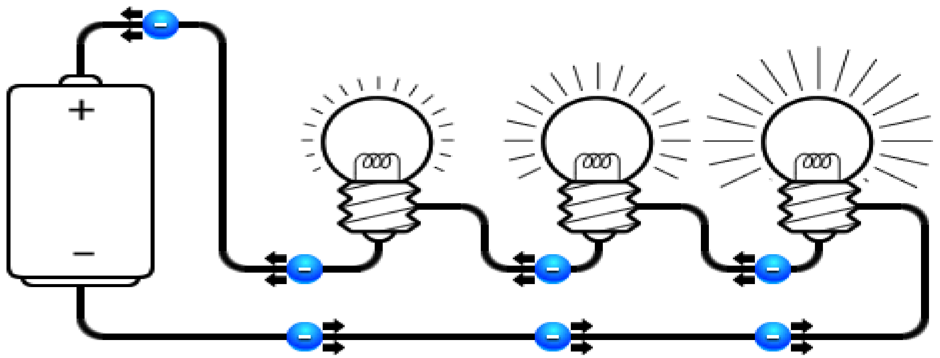


Series Connection

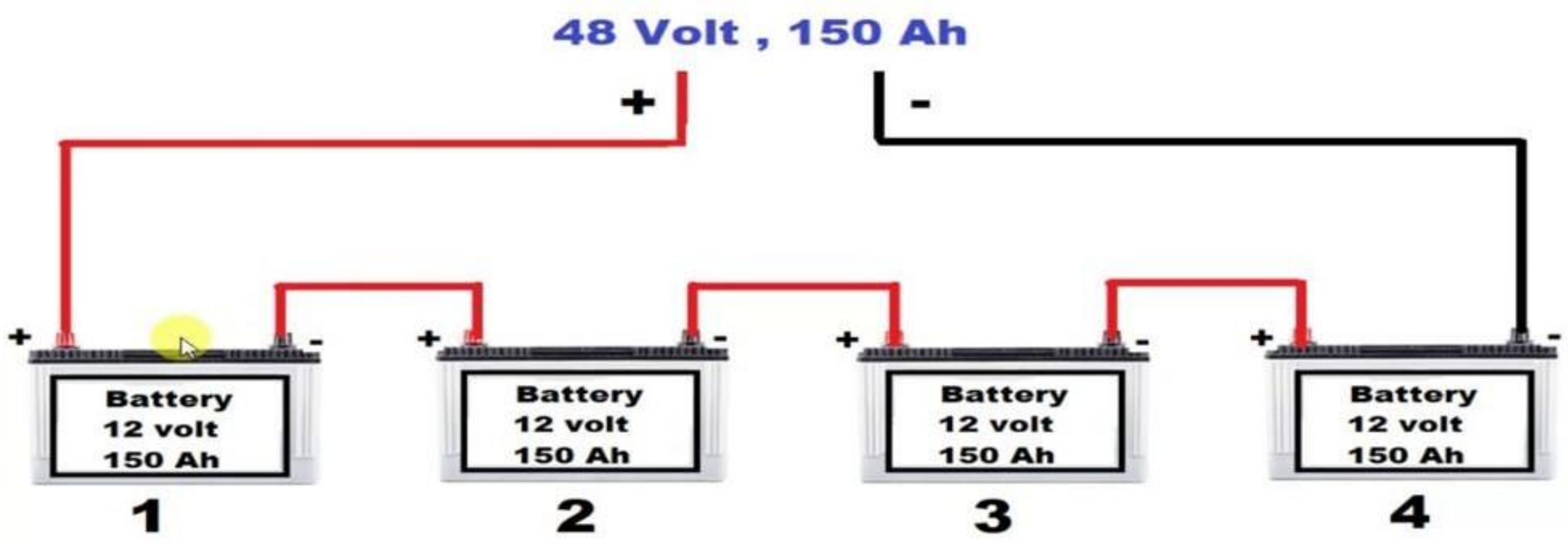
- **SERIES CONNECTION:** Two or more elements are in series if they exclusively share a single node and consequently carry the same current.







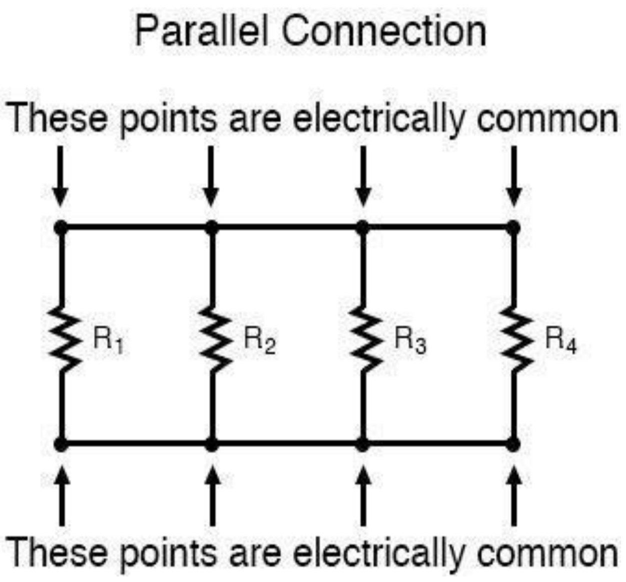
Point to Remember for Series Circuits

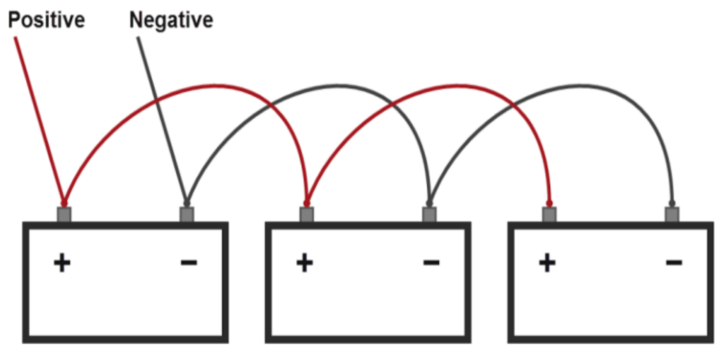


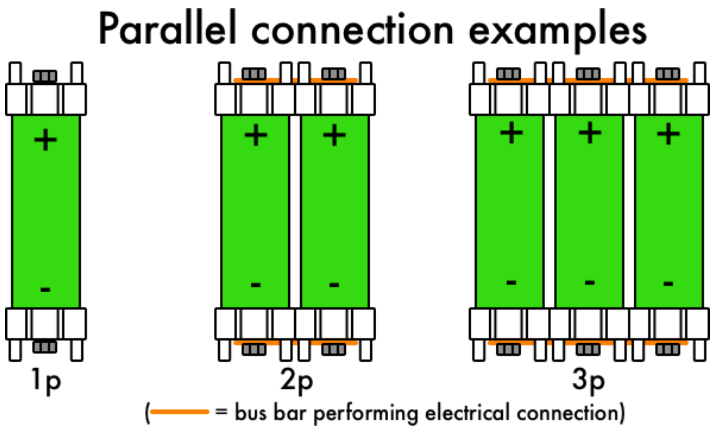
In Series System Voltage are Added & Current are Same

Parallel Connection

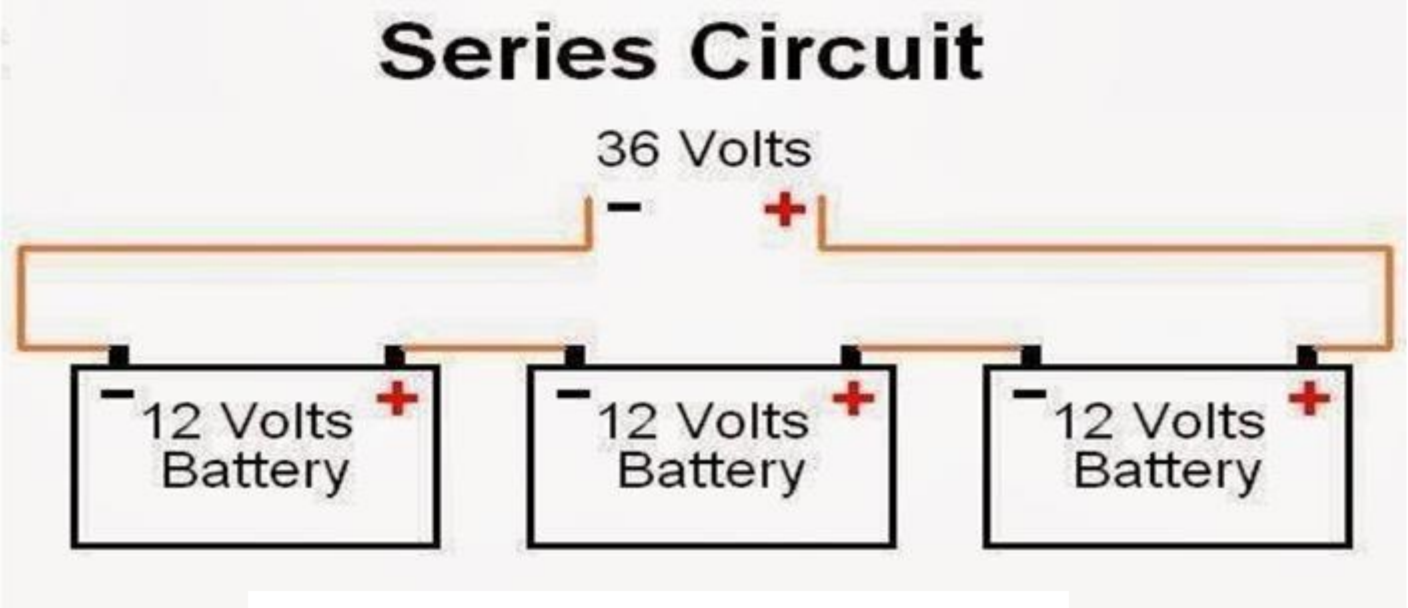
- PARALLEL CONNECTION: Two or more elements are in parallel if they are connected to the same two nodes and consequently have the same voltage across them

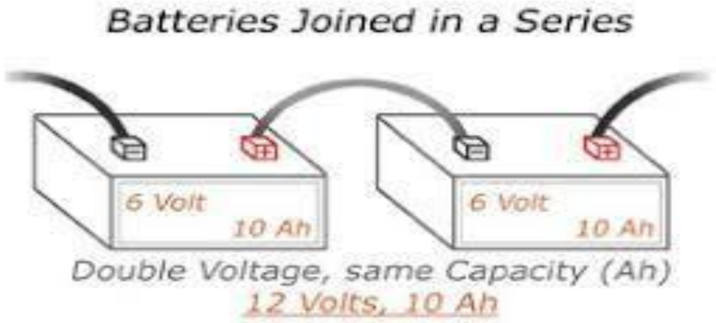


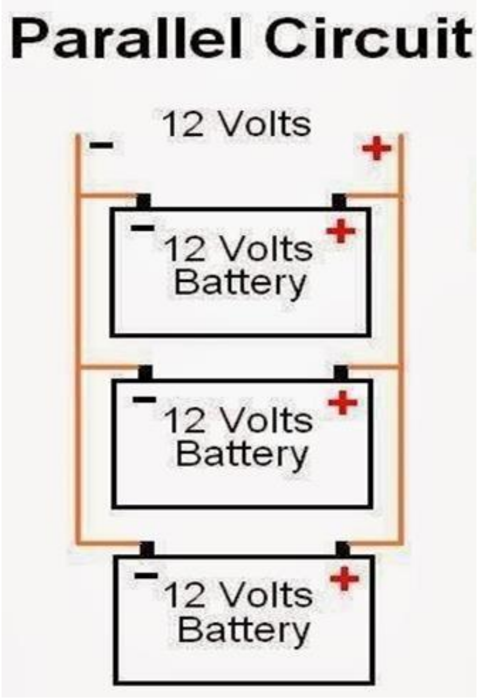


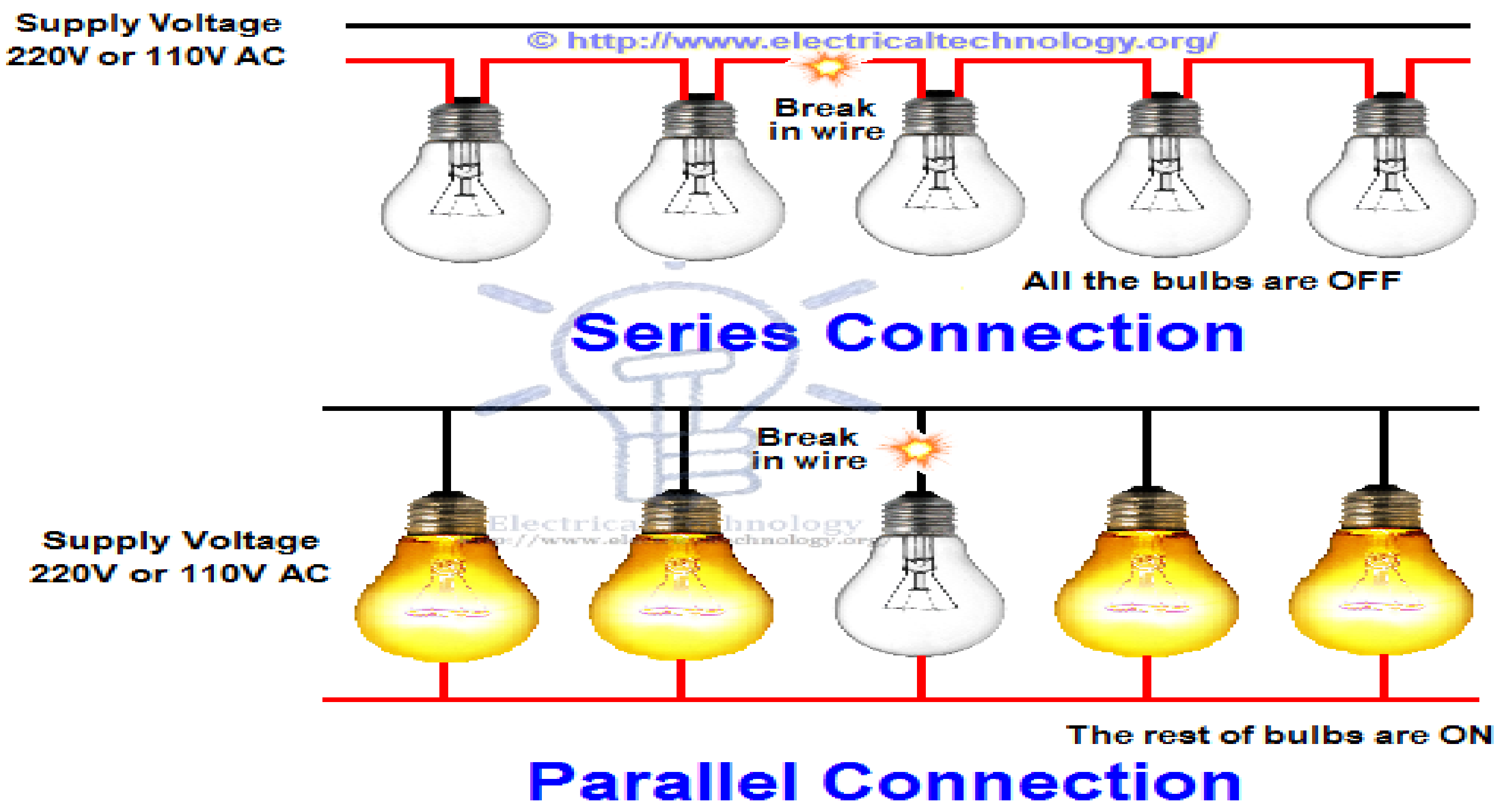


Battery Voltage In Series And Parallel









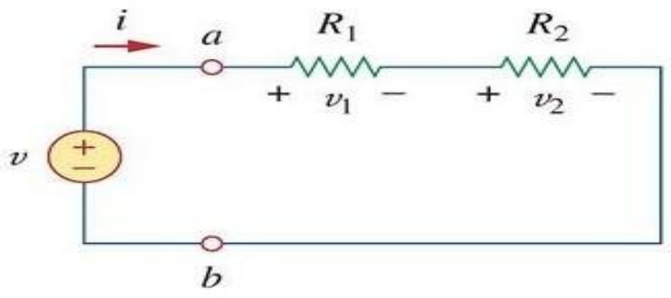
Why Parallel Connection is Preferred over Series Connection?

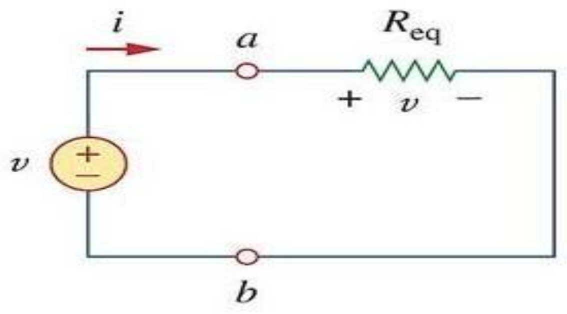
RESISTORS IN SERIES

Series: Two or more elements are in series if they are cascaded or connected sequentially and consequently carry the same current.

The equivalent resistance of any number of resistors connected in a series is the sum of the individual resistances

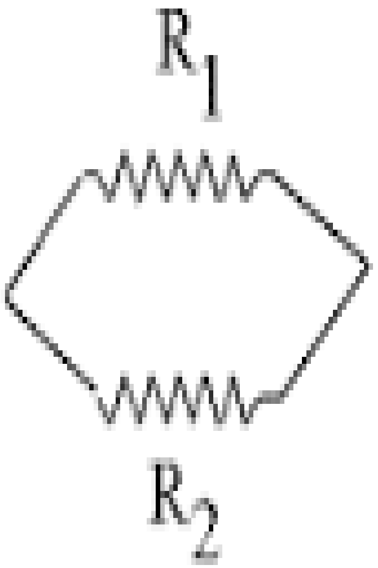
$$R_{eq} = R_1 + R_2 + \cdots + R_N = \sum_{n=1}^{N} R_n$$





Note: Resistors in series behave as a single resistor whose resistance is equal to the sum of the resistances of the individual resistors.

Resistors in Parallel



$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2}$$

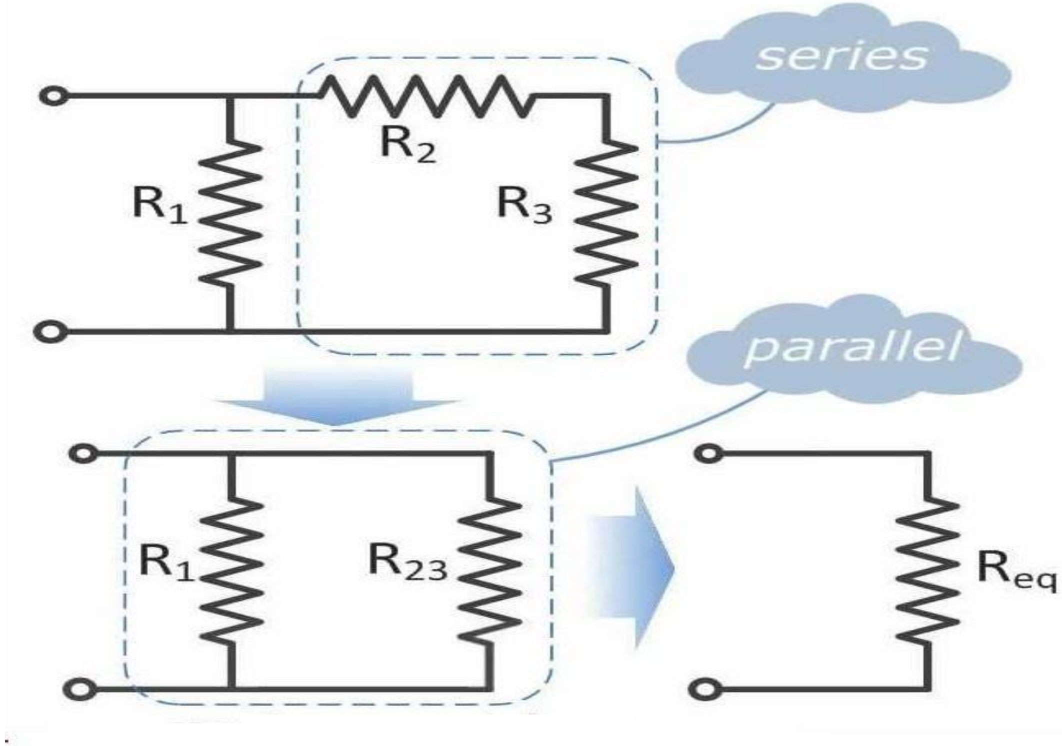
$$\frac{1}{R_t} = \frac{R_2 + R_1}{R_1 R_2}$$

$$\boxed{R_t = \frac{R_1 R_2}{R_2 + R_1}}$$

The equivalent of two parallel resistor is equal to their product divided by their sum.

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N}$$

How to find Equivalent Resistance for Series-Parallel Combinations



$$R_{23} = R_2 + R_3$$

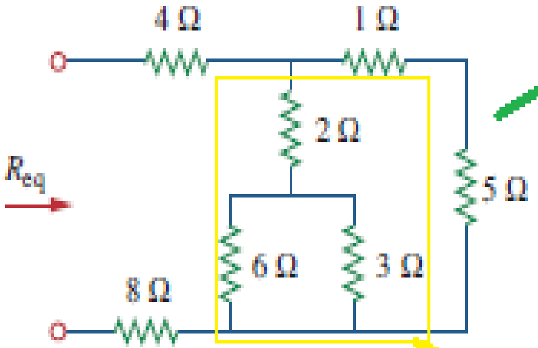
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_{23}}$$

$$R_{eq} = \frac{R_1 \cdot R_{23}}{R_1 + R_{23}}$$

$$R_{eq} = \frac{R_1(R_2 + R_3)}{R_1 + R_2 + R_3}$$

Example: To find R_{eq}

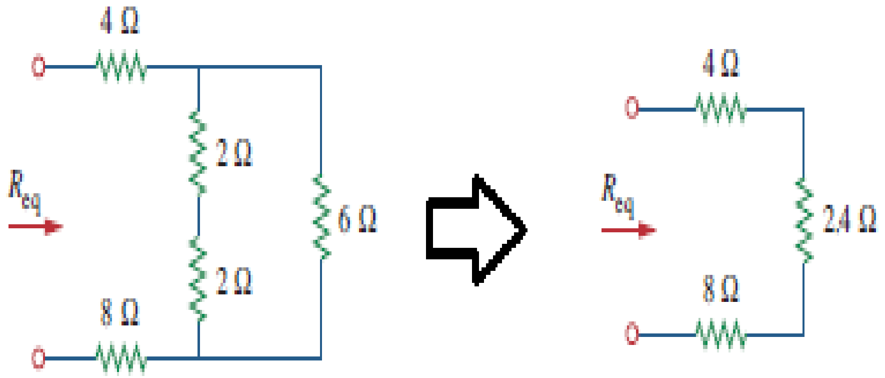
Find R_{eq} for the circuit shown in Fig.



$1\ \Omega + 5\ \Omega = 6\ \Omega$

$2\ \Omega + 2\ \Omega = 4\ \Omega$

$$6\ \Omega \parallel 3\Omega = \frac{6 \times 3}{6 + 3} = 2\ \Omega$$



$$4\Omega \parallel 6\Omega = \frac{4 \times 6}{4 + 6} = 2.4\ \Omega$$

$$R_{eq} = 4\ \Omega + 2.4\ \Omega + 8\ \Omega = 14.4\ \Omega$$

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Useful Links

- http://www.dynamicscience.com.au/tester/solutions1/electric/voltage.htm
- https://gfycat.com/directhauntinglamb
- https://www.youtube.com/watch?v=NfcgA1axPLo