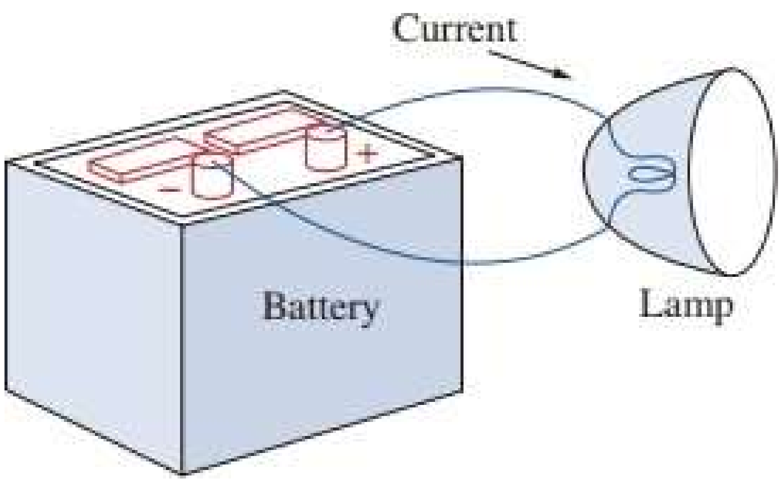
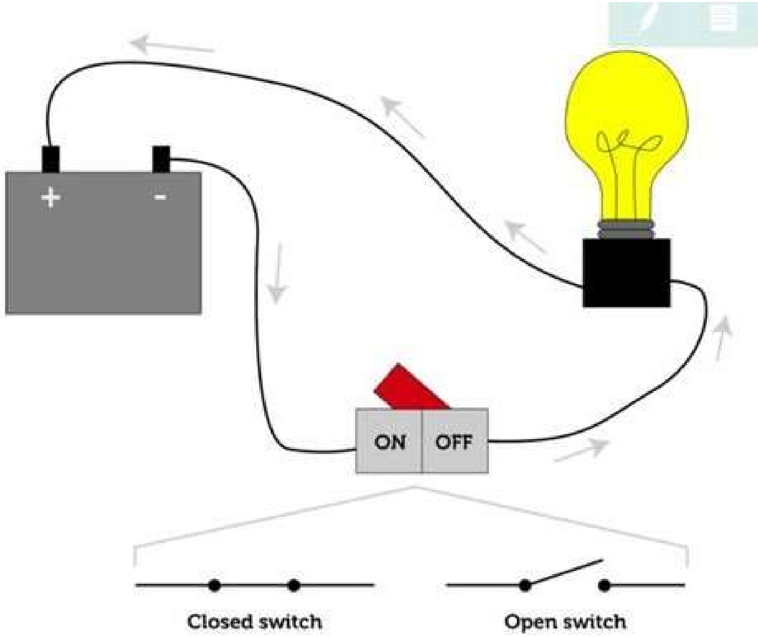
UNIT 1:
DC CIRCUITS

Electrical Circuit



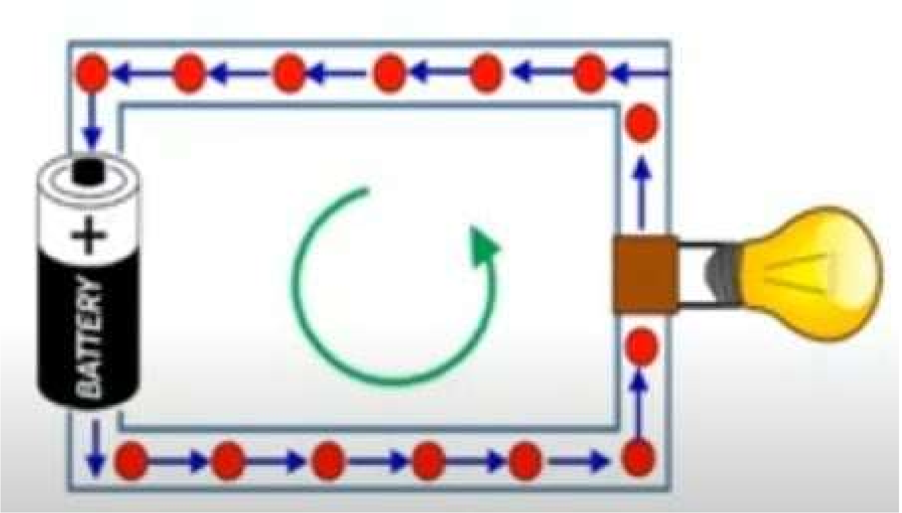


Charge and Current

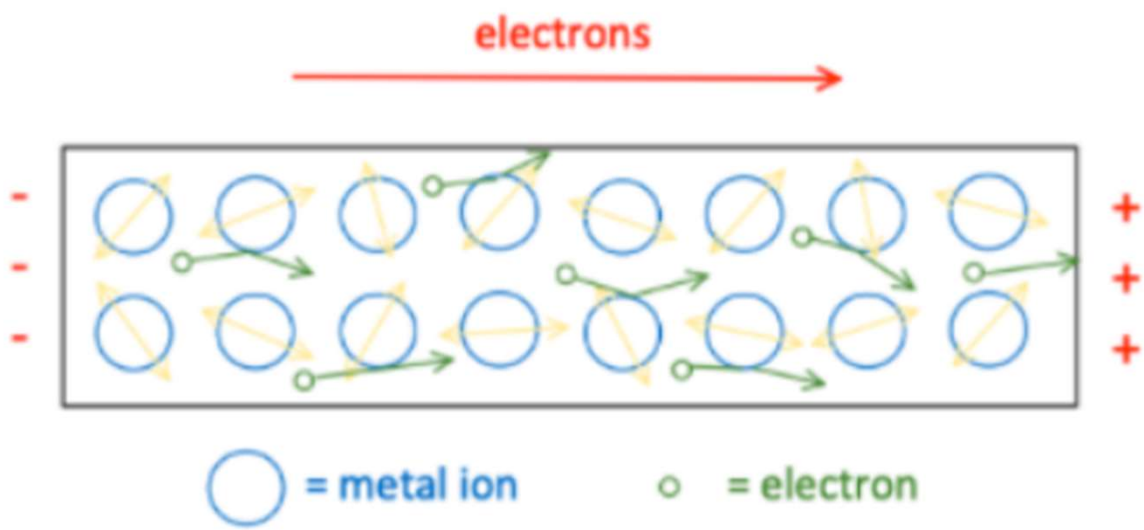
Charge: Charge is an electrical property of the atomic particles of a matter.
S.I Unit: Coulomb (C), Symbol: Q

Current: Rate of change of charge. Continuous flow of electrons in an electrical circuit.
S.I Unit: Ampere (A), Symbol: I

- **A potential difference is needed for charge to flow.** If you have an ordinary metal wire without a cell or battery, the electrons move randomly, and there is no net flow of charge. When a cell or battery – a **potential difference / voltage** – is applied to the metal wire, the electrons move away from the negative terminal and towards the positive terminal. There is a net flow of charge – an electric current.



Current in metals is the flow of negatively charged electrons. Electrons can move from one atom to another, forming a sea of **delocalised electrons.**



Electrical Charge

Charge and Current

- Mathematically,

$$I = \frac{dQ}{dt} \ or \ Q = \int_{t_0}^{t} I.dt$$

Or, in simple terms:

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

So, 1 Ampere = 1 coulomb/ 1 second.

QUICK QUIZ (Poll 1)

1 Coulomb is same as:

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

QUICK QUIZ (Poll 2)

The total charge entering the terminal is $5\mathrm{t} sin 4\pi t\ mC$. Calculate current at t= 0.5 sec.:

A. 31.42 A

B. 31.42 mA

C. 62.8 mA

D. 62.8 A

QUICK QUIZ (Poll 2)

The total charge entering the terminal is $5\mathrm{t}sin4\pi t\ mC$. Calculate current at t= 0.5 sec.:

A. 31.42 A
B. 31.42 mA
C. 62.8 mA
D. 62.8 A

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

$q(t) = 5t\sin(4\pi t)\,\mathrm{mC}$

The current $i(t)$ is the derivative of the charge $q(t)$ with respect to time t:

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

Let's find the derivative of $q(t) = 5t\sin(4\pi t)$.

Using the product rule, where $u(t) = 5t$ and $v(t) = \sin(4\pi t)$:

$\frac{d}{dt}[u(t)v(t)] = u'(t)v(t) + u(t)v'(t)$

First, find the derivatives:

$u'(t) = 5$
$v'(t) = 4\pi\cos(4\pi t)$

Now, apply the product rule:

$\frac{dq(t)}{dt} = 5\sin(4\pi t) + 5t \cdot 4\pi\cos(4\pi t)$
$i(t) = 5\sin(4\pi t) + 20\pi t\cos(4\pi t)$

Next, evaluate this expression at $t = 0.5$ seconds:

$$i(0.5) = 5\sin(4\pi \cdot 0.5) + 20\pi \cdot 0.5\cos(4\pi \cdot 0.5)$$

Simplify the trigonometric functions:

$$\sin(4\pi \cdot 0.5) = \sin(2\pi) = 0$$
$$\cos(4\pi \cdot 0.5) = \cos(2\pi) = 1$$

Substitute these values into the expression:

$$i(0.5) = 5 \cdot 0 + 20\pi \cdot 0.5 \cdot 1$$
$$i(0.5) = 10\pi$$

Therefore, the current at $t = 0.5$ seconds is:

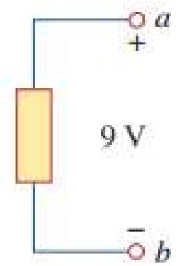
$$i(0.5) = 10\pi\,\mathrm{mA}$$

This simplifies to approximately:

$$i(0.5) \approx 31.42\,\mathrm{mA}$$

Voltage

- It is the energy (Work) required to move a unit charge through an element.
- S.I Unit: Volt (V) Symbol: V
- As per voltage definition, it is the difference in the electric potential between two points.
- It is the work done in moving a charge from one pole to another through a wire



(a)

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

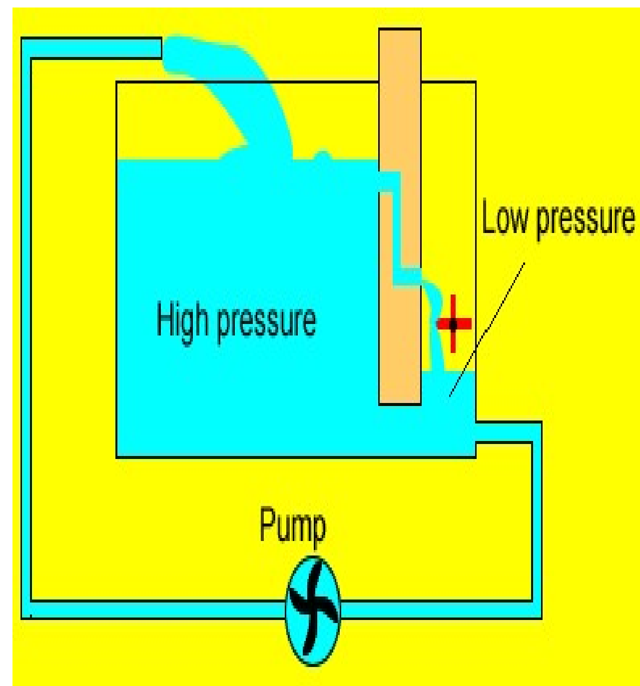
$$1 \text{ volt} = 1 \text{ joule/coulomb}$$

•To determine the voltage between any two points, both a static electric field and a dynamic electromagnetic field is considered.

•The mathematical representation of voltage is as follows:

$$V = IR$$

V = Voltage in volts
I = Current in amperes
R = Resistance in ohms



Power and Energy

- **Power:** Rate at which the work is done. Time rate of absorbing or supplying energy.

  S.I Unit: Watts (W) ; Symbol: P

Mathematically,

$$P = \frac{W}{t}$$

W = Work done | t = Time taken | P = Power

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

$$W = V \cdot Q \qquad I = \frac{dQ}{dt}$$

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

Power and Energy

- **Energy** is the ability to perform work. Energy can neither be created nor destroyed, and it can only be transformed from one form to another. The unit of Energy is the same as of Work, i.e. Joules. Energy is found in many things, and thus, there are different types of energy.
- All forms of energy are either **kinetic or potential**. The energy in motion is known as Kinetic Energy, whereas Potential Energy is the energy stored in an object and is measured by the amount of work done.

- 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 = 0.454 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

QUICK QUIZ (Poll 4)

From the previous question, it can be inferred that:

A. LED consumes 5 times more current than Bulb.

B. Bulb consumes 5 times more current than LED..

C. LED consumes 6.6 times more current than Bulb.

D. Bulb consumes 6.6 times more current than LED.

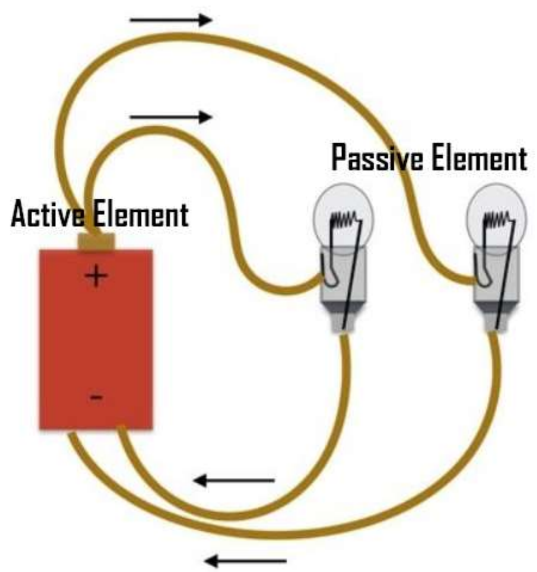
Network Components

Active: can deliver and absorb the power

- Battery
- Transistor,
- Op-amp,
- Diode
- Generators

Passive: not able to deliver power

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

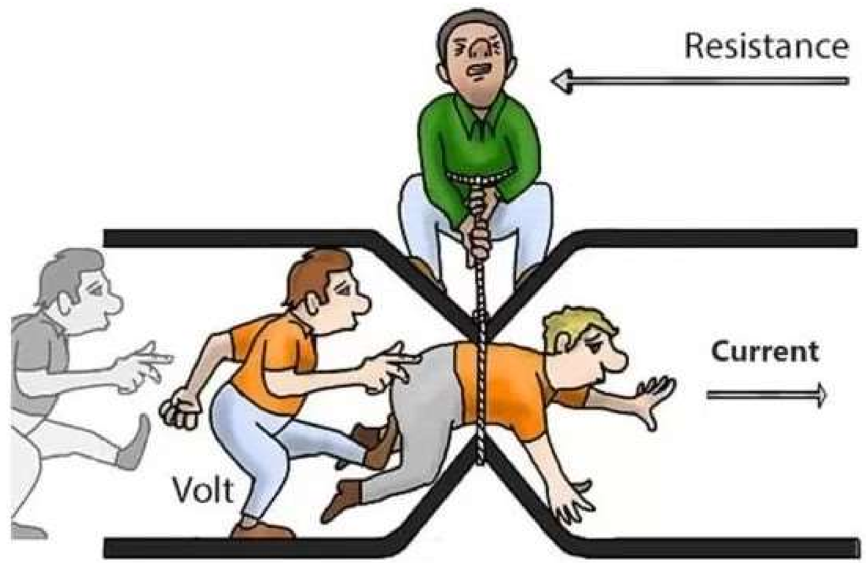


Resistance

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

  S.I Unit: Ohm (Ω)

  Symbol: R

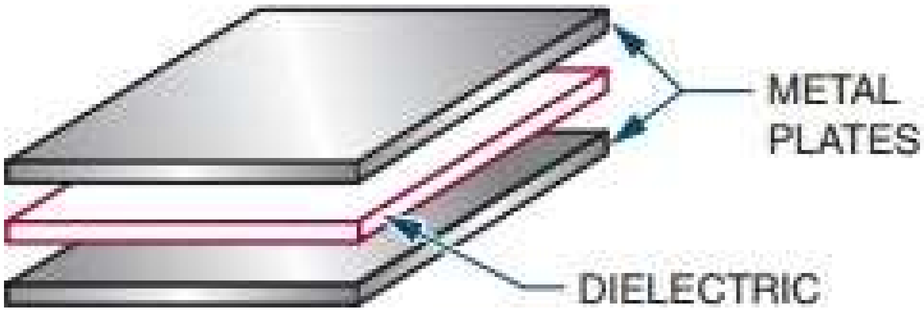


Capacitance

- 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:

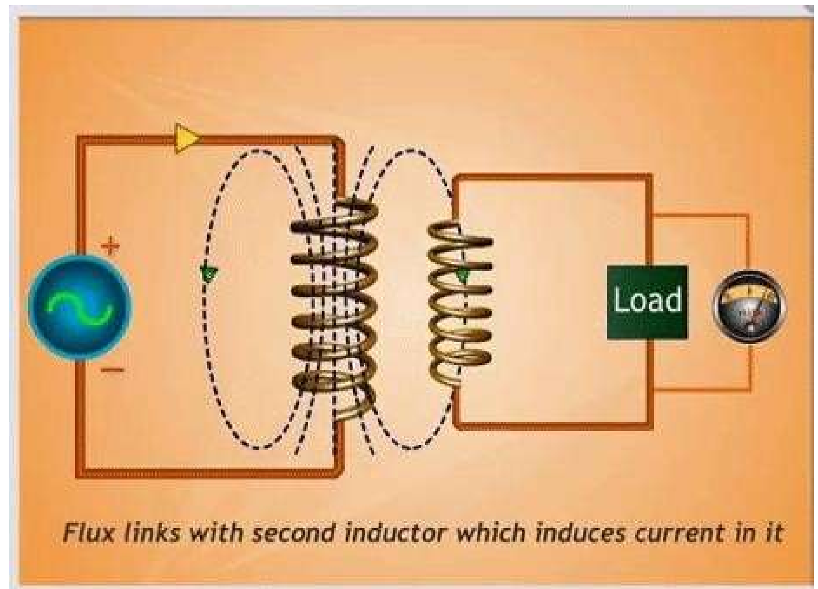
1. No current flows through the capacitor, if the voltage remains constant.
2. Voltage across a capacitor cannot change instantaneously.

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



Flux links with second inductor which induces current in it

Two important Properties:

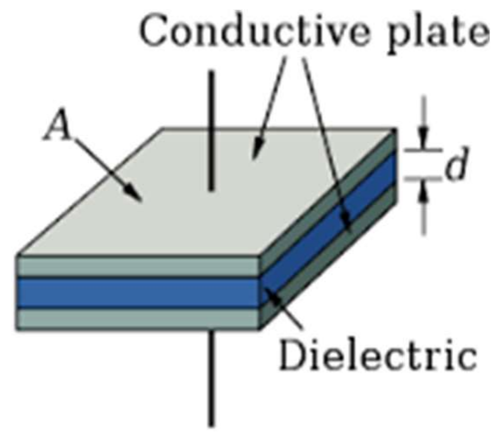
1. No voltage appears across an inductor, if the current through it remains constant.
2. The current through an inductor cannot change instantaneously.

Capacitance and Inductance

- $Q = CV$ (C is capacitance and V is Voltage)

- $I = \frac{dQ}{dt} = \frac{d\,CV}{dt} = C\,\frac{dV}{dt}$
- $E = \frac{1}{2}CV^{\,2}$

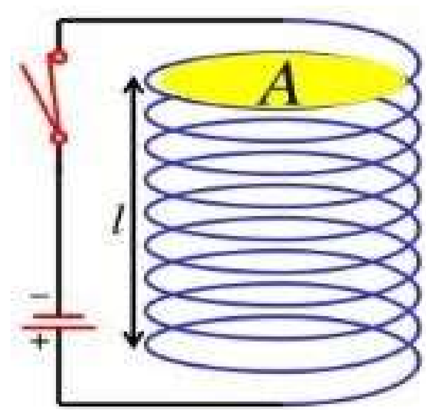
- $V = L\,\frac{dI}{dt}$
- $E = \frac{1}{2}\,LI^2$



$C = \frac{\varepsilon A}{d}$

Where:

- C is the capacitance,
- ε is the permittivity of the material between the capacitor plates,
- A is the area of one of the capacitor plates,
- d is the separation (distance) between the capacitor plates.



(L is length of coil)

QUICK QUIZ (Poll 5)

Identify the passive element.

A. Battery
B. Transformer
C. Transistor
D. OP-amp

QUICK QUIZ (Poll 6)

Find the value of capacitance if the value of voltage increases linearly from 0 to 100 V in 0.1 s causing a current flow of 5 mA?

A. 10 μF

B. 5 F

C. 10 F

D. 5 μF

$I(t) = C\frac{dV(t)}{dt}$

where:

- $I(t)$ is the current as a function of time,
- $V(t)$ is the voltage as a function of time,
- C is the capacitance.

In this case, you're given that the voltage increases linearly from 0 to 100 V in 0.1 s, which can be expressed as:

$V(t) = \frac{100}{0.1}t$

Now, we can find the derivative of $V(t)$ with respect to time ($\frac{dV(t)}{dt}$):

$\frac{dV(t)}{dt} = \frac{100}{0.1}$

Given that the current ($I(t)$) is 5 mA (0.005 A), you can substitute these values into the capacitance formula:

$0.005 = C \times \frac{100}{0.1}$

Now, solve for C:

$C = \frac{0.005}{\frac{100}{0.1}}$

$C = \frac{0.005 \times 0.1}{100}$

$C = \frac{0.0005}{100}$

$C = 5 \times 10^{-6}$

Therefore, the capacitance is $5\mu F$.

Ohm’s Law

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- 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”

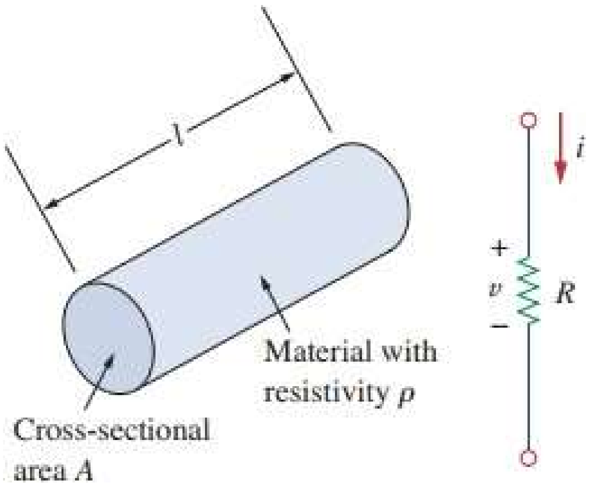
Mathematically,

$$I \propto V$$

Or,

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

Where, Resistance $R = \rho \frac{l}{A}$



Resistivity Table

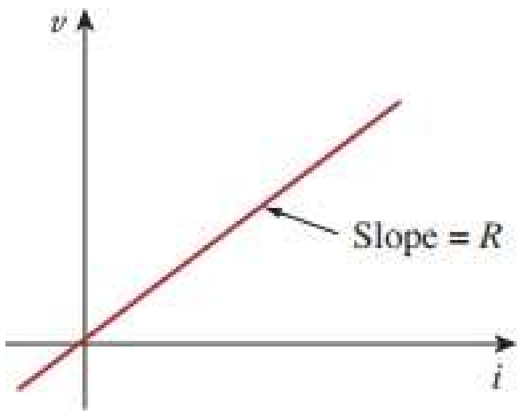
Material	Resistivity ($\Omega \cdot m$)	Usage
Silver	1.64×10^{-8}	Conductor
Copper	1.72×10^{-8}	Conductor
Aluminum	2.8×10^{-8}	Conductor
Gold	2.45×10^{-8}	Conductor
Carbon	4×10^{-5}	Semiconductor
Germanium	47×10^{-2}	Semiconductor
Silicon	6.4×10^{2}	Semiconductor
Paper	10^{10}	Insulator
Mica	5×10^{11}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

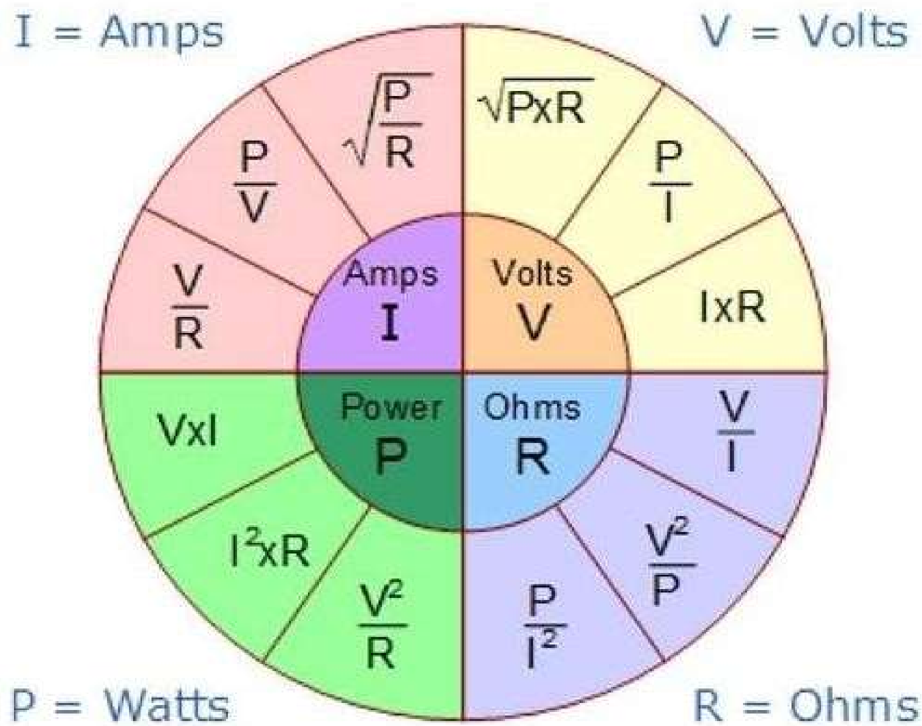
Conductance

- 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.

- Power dissipated in the resistor can be expressed as:

- $P = VI = I^2R = \frac{V^2}{R}$

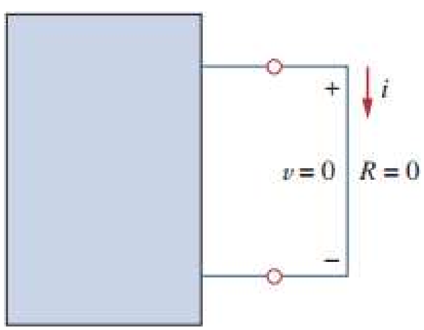




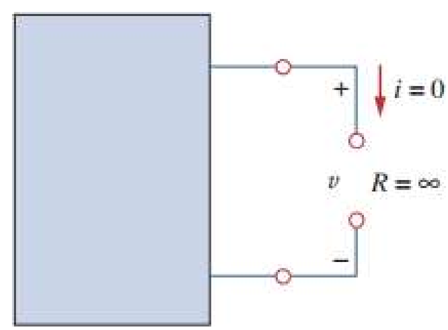
Ohm's Law Pie Chart (Source: Electronics-Tutorials.ws)

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** $\boxed{R = \rho\frac{\ell}{A}}$

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's working principles 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.

QUICK QUIZ (Poll 7)

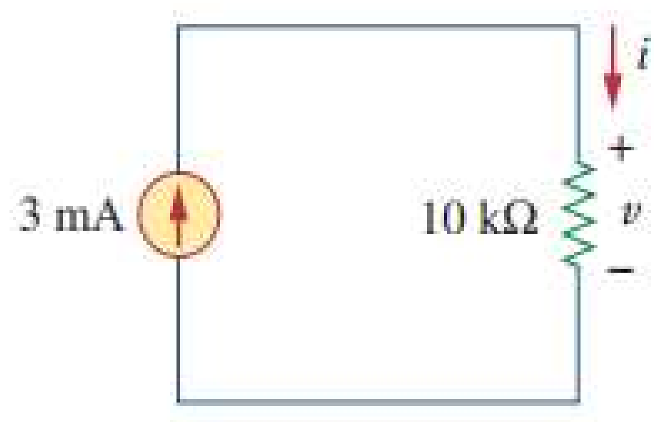
The voltage and the conductance of the given circuit is:

A. 30 V, 10 µS

B. 30 mV, 100 µS

C. 30 V, 100 µS

D. 30 mV, 10 µS



Law to find the voltage (V):

$$V = (3 \times 10^{-3})\,\mathrm{A} \times (10 \times 10^{3})\,\Omega$$

$$V = 30\,\mathrm{V}$$

So, if the current is $3\,\mathrm{mA}$ and the resistance is $10\,\mathrm{k}\Omega$, the voltage across the circuit would be $30\,\mathrm{V}$.

Now, conductance (G) is the reciprocal of resistance and is measured in Siemens (S). The formula for conductance is:

$$G = \frac{1}{R}$$

So, for the given resistance of $10\,\mathrm{k}\Omega$:

$$G = \frac{1}{10 \times 10^{3}}\,\mathrm{S}$$

$$G = 10^{-4}\,\mathrm{S}$$

Therefore, the conductance would be $10^{-4}\,\mathrm{S}$.

QUICK QUIZ (Poll 8)

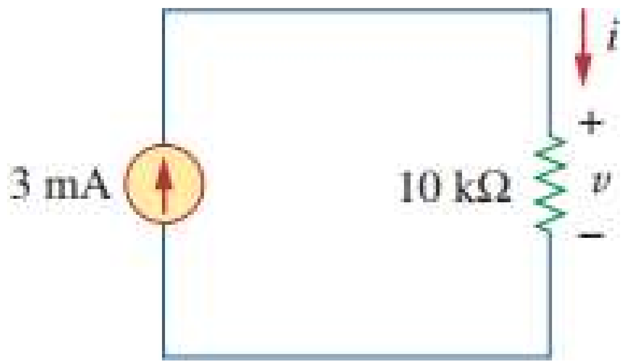
The power of the given circuit is:

A. 60 mW

B. 70 mW

C. 80 mW

D. 90 mW



The power (P) can be calculated using the formula:

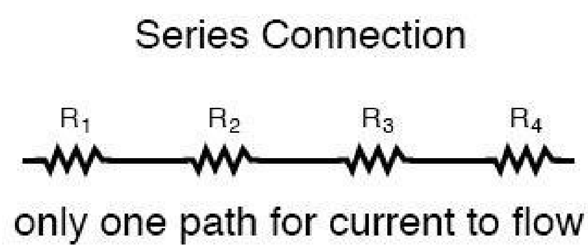
$$P = I^2 \cdot R$$

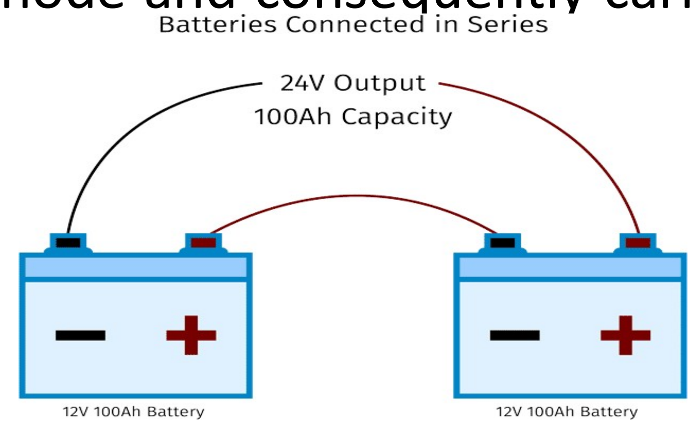
$$P = (3 \times 10^{-3})^2\,\mathrm{A} \times (10 \times 10^3)\,\Omega$$

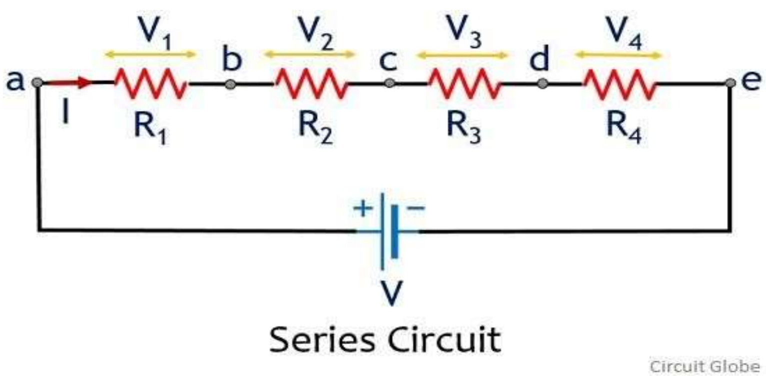
$$P = 0.09\,\mathrm{W}$$

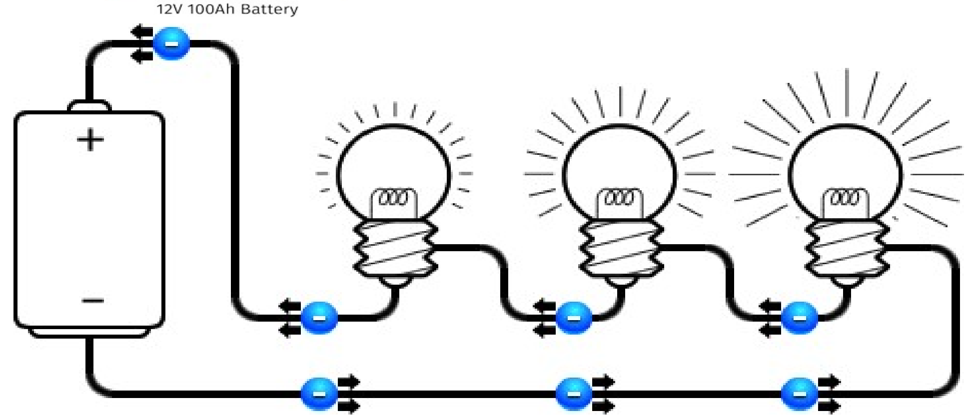
Series Connection

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

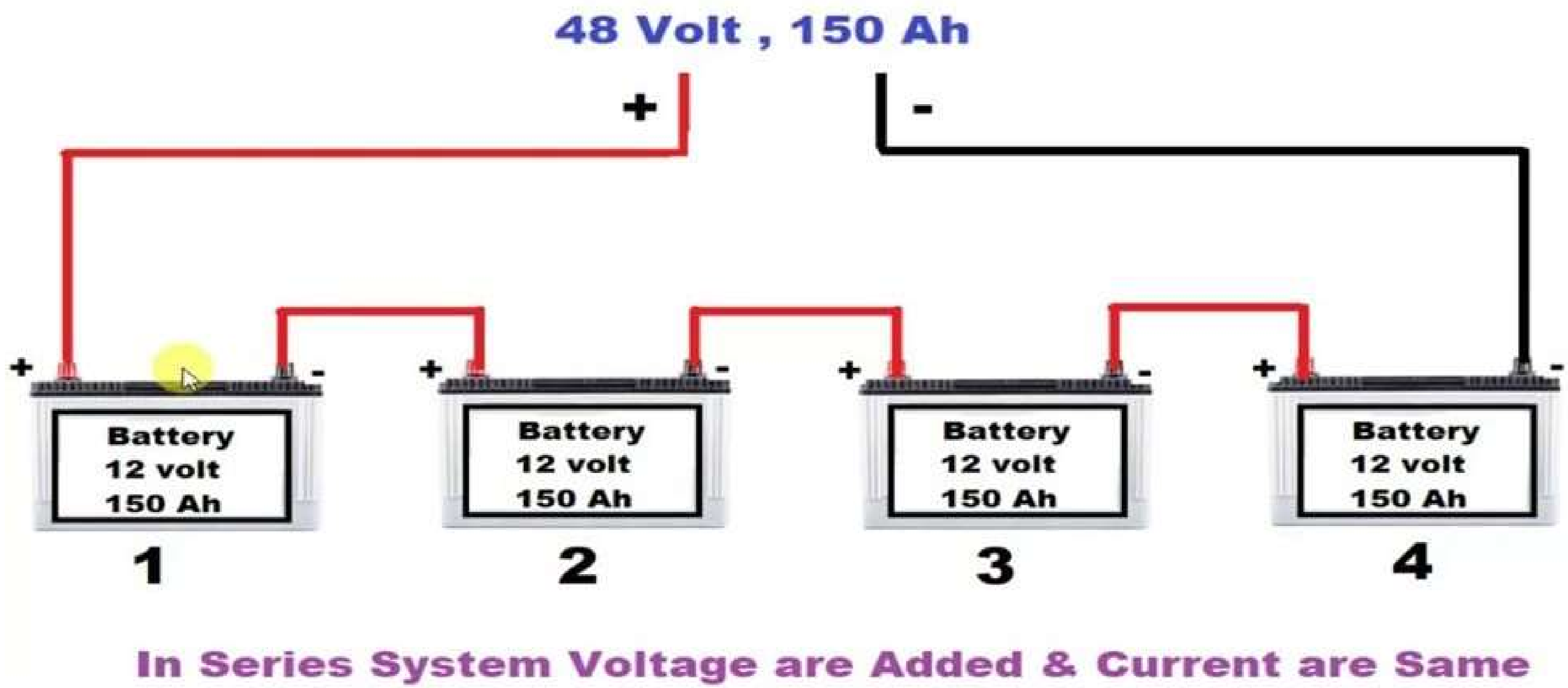






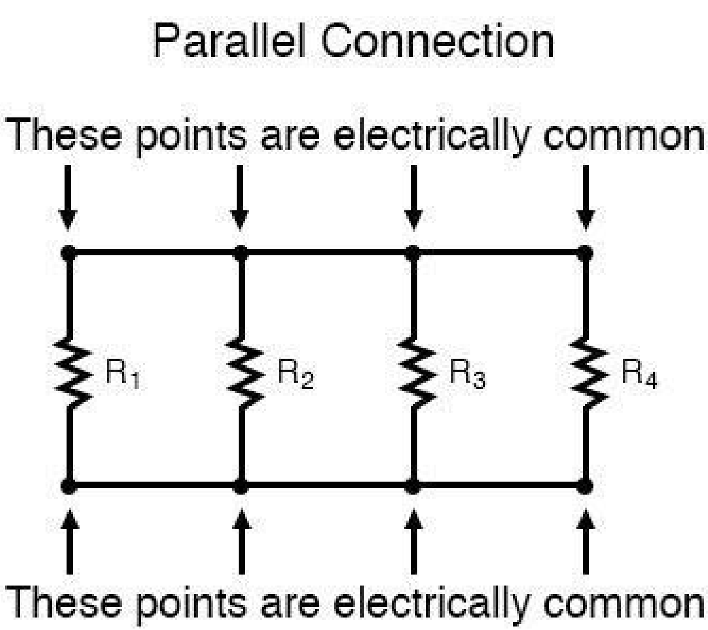


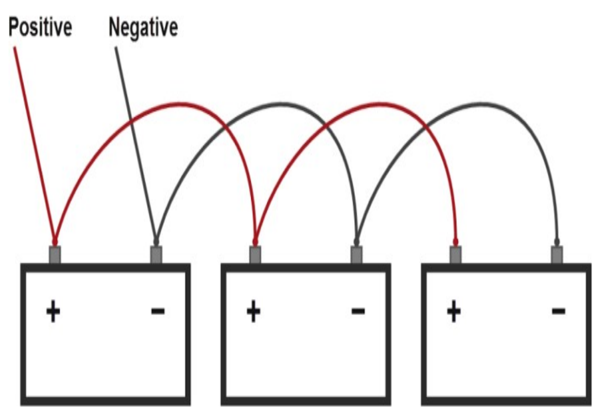
Point to Remember for Series Circuits

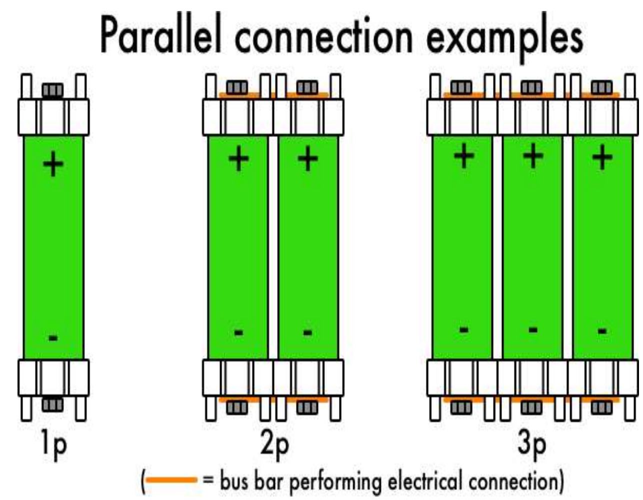


Parallel Connection

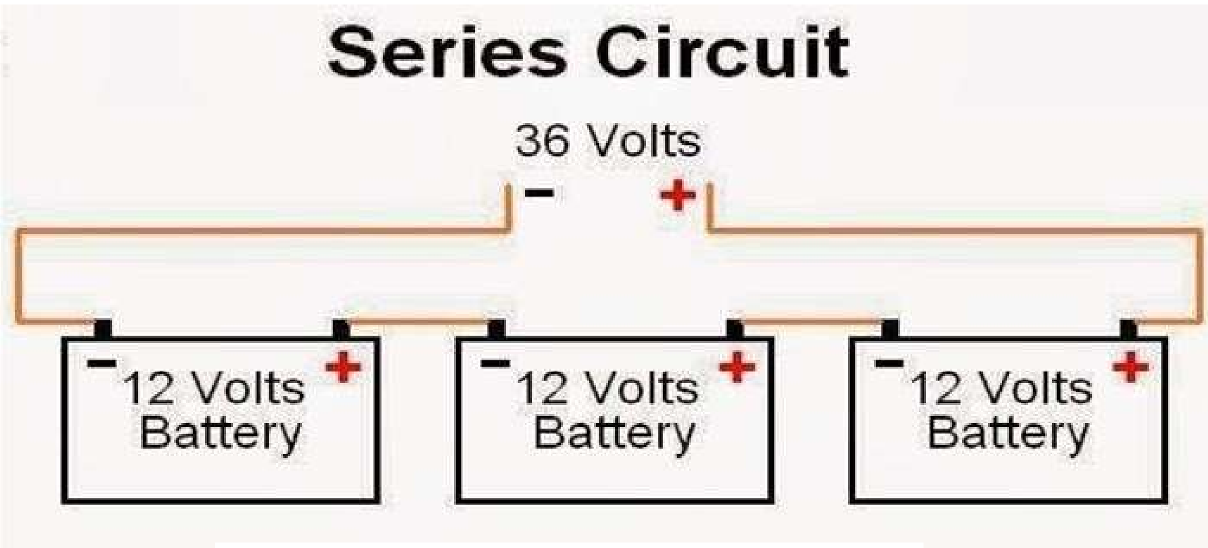
- PARALLEL CONNECTION: Two or more elements are in parallel if they are connected to the same two nodes and consequently have the same voltage across them.

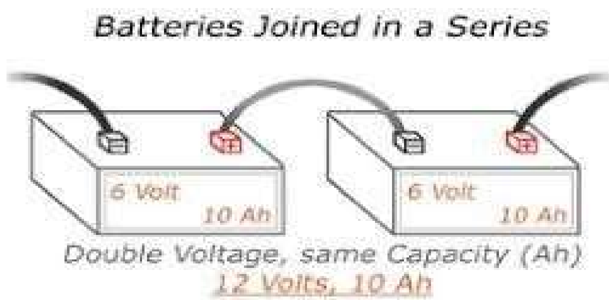


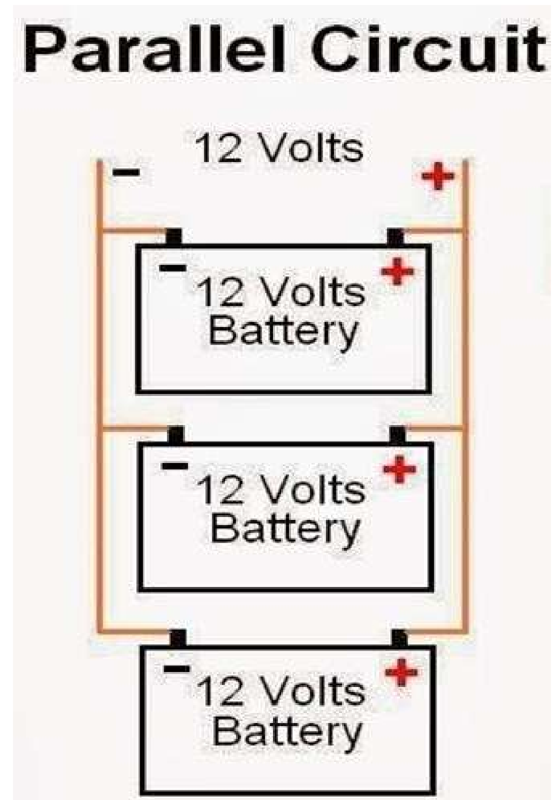


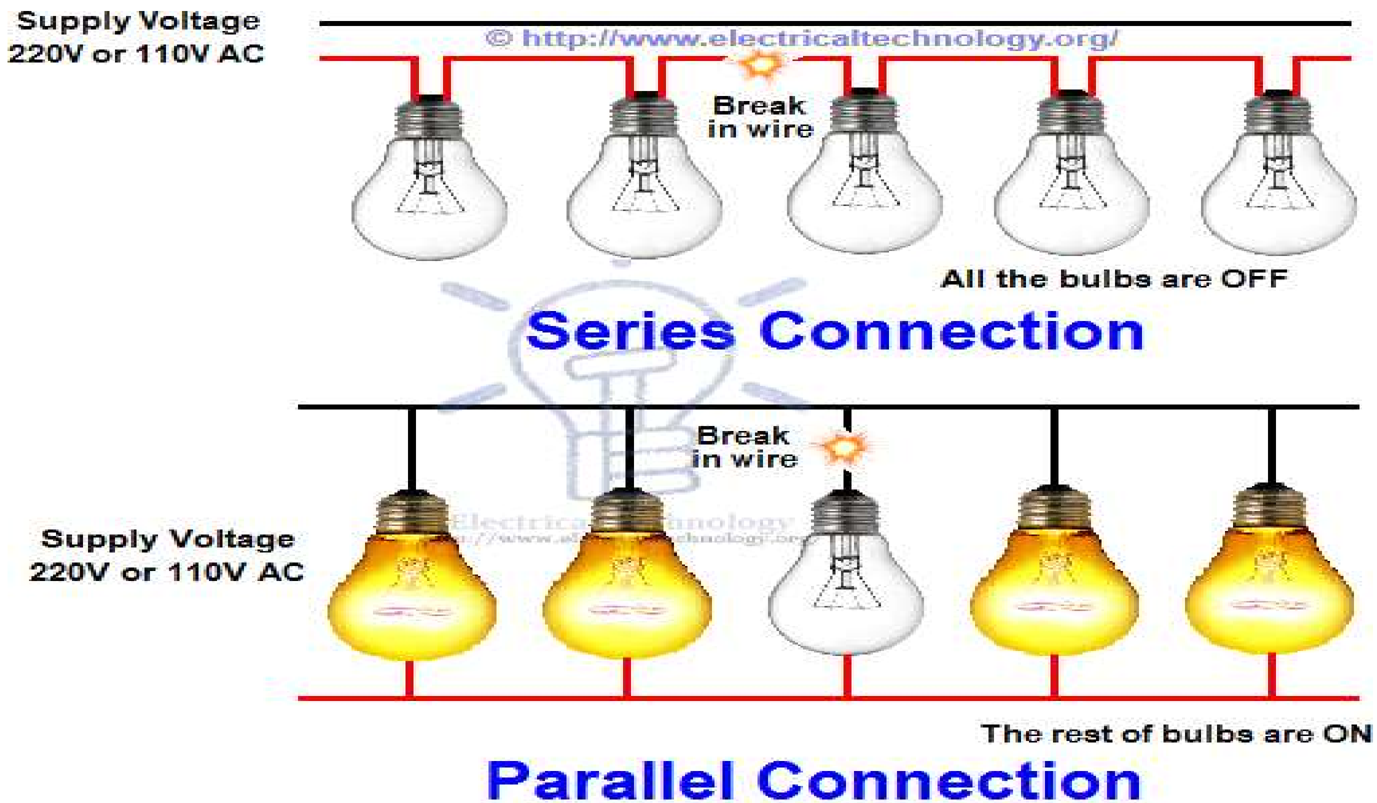


Battery Voltage In Series And Parallel









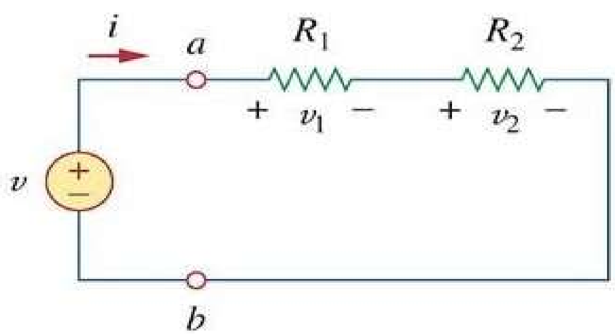
Why Parallel Connection is Preferred over Series Connection?

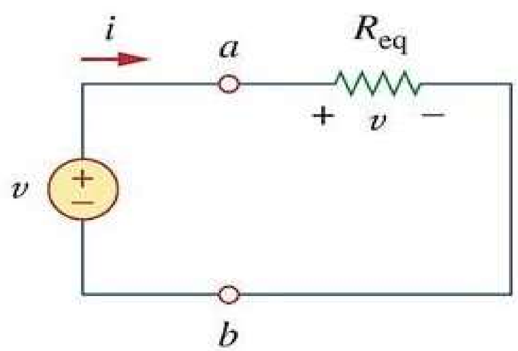
RESISTORS IN SERIES

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

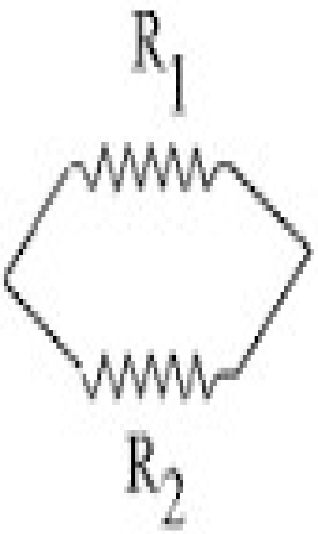
$$R_{eq} = R_1 + R_2 + \cdots + R_N = \sum_{n=1}^{N} R_n$$





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



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

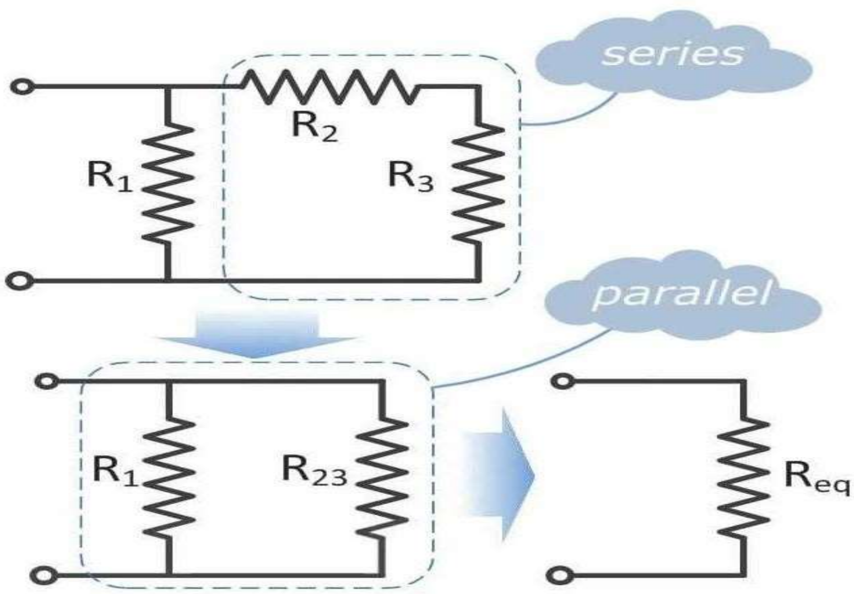
$$\frac{1}{R_t} = \frac{R_2 + R_1}{R_1 R_2}$$

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

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



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

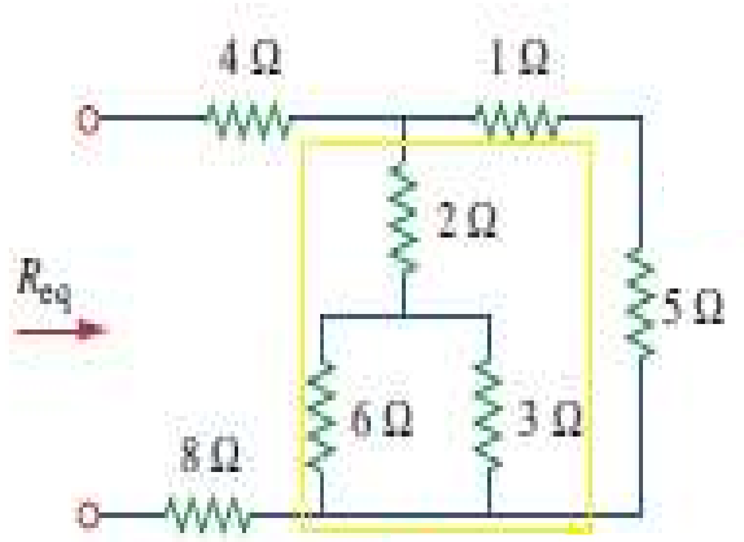
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_{23}}$$

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

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

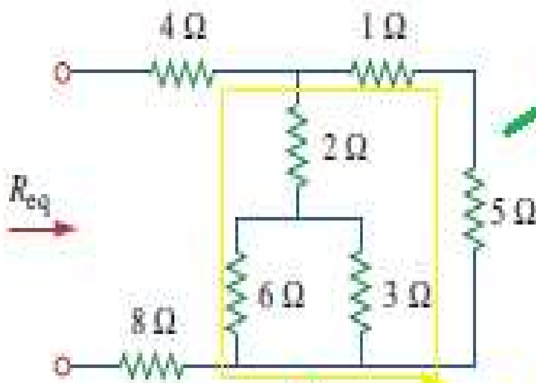
Example: To find $\boldsymbol{R_{eq}}$

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



Example: To find $\boldsymbol{R_{eq}}$

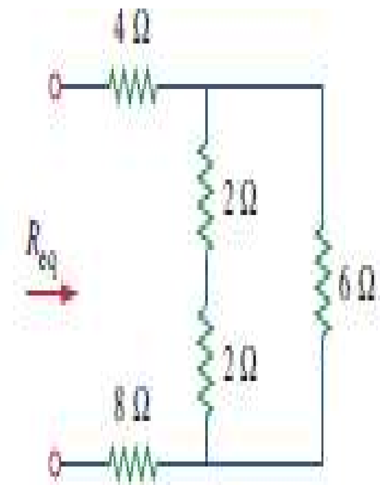
Find R_{eq} for the circuit shown in Fig.



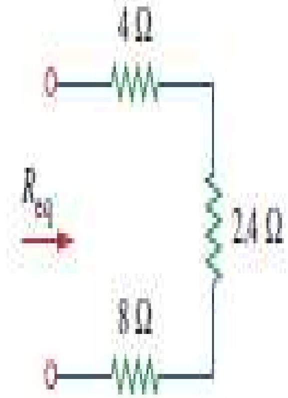
$$1\,\Omega + 5\,\Omega = 6\,\Omega$$

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

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



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

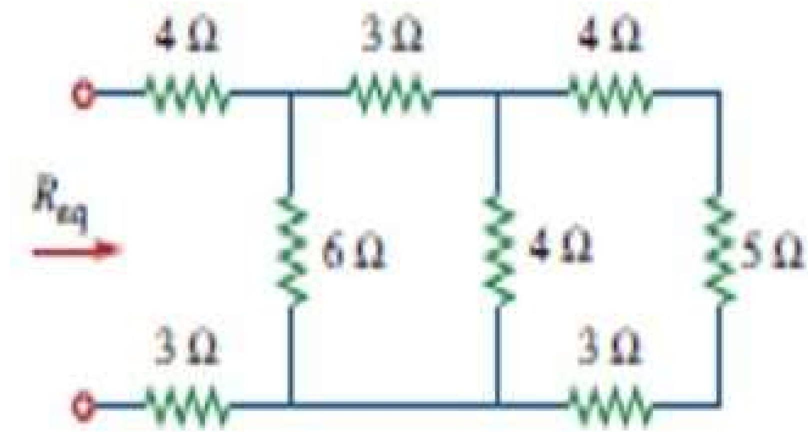


$$R_{eq} = 4\Omega + 2.4\Omega + 8\Omega = 14.4\Omega$$

QUICK QUIZ (Poll 9)

Find Equivalent Resistance in Ohms?

A. 5
B. 10
C. 15
D. 20



QUICK QUIZ (Poll 10)

Find Equivalent Resistance in Ohms?

A. 12
B. 17
C. 19
D. 29