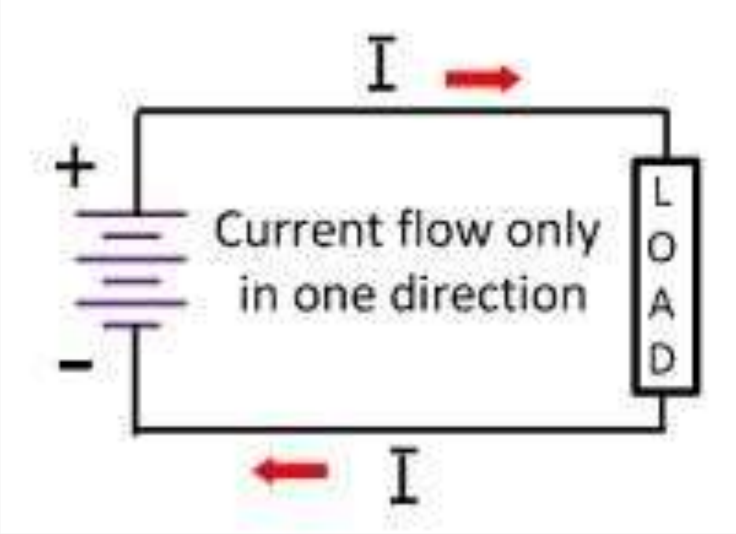
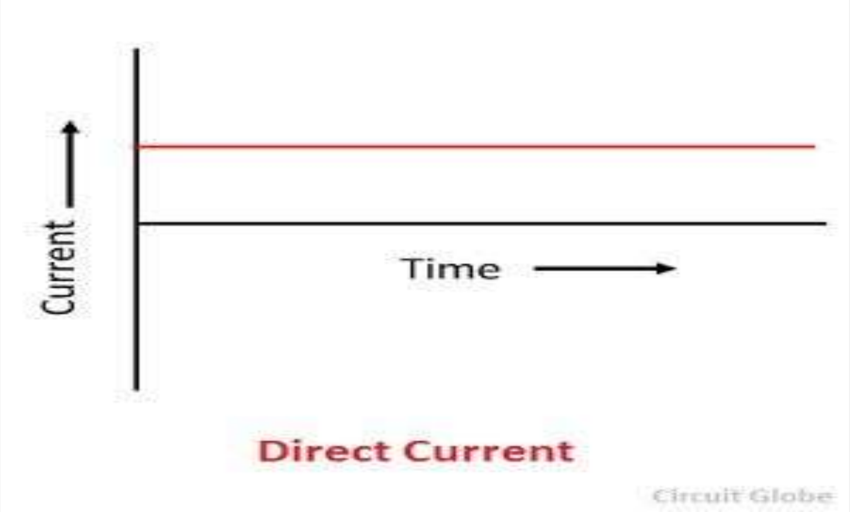
UNIT – I
DC CIRCUITS

Voltage and current sources, dependent and independent sources, Units and dimensions, Source Conversion, Ohm's Law, Kirchhoff's Law, Superposition theorem, Thevenin's theorem and their application for analysis of series and parallel resistive circuits excited by independent voltage sources, Power & Energy in such circuits. Mesh & nodal analysis, Star Delta transformation & circuits.

DC (Direct Current)

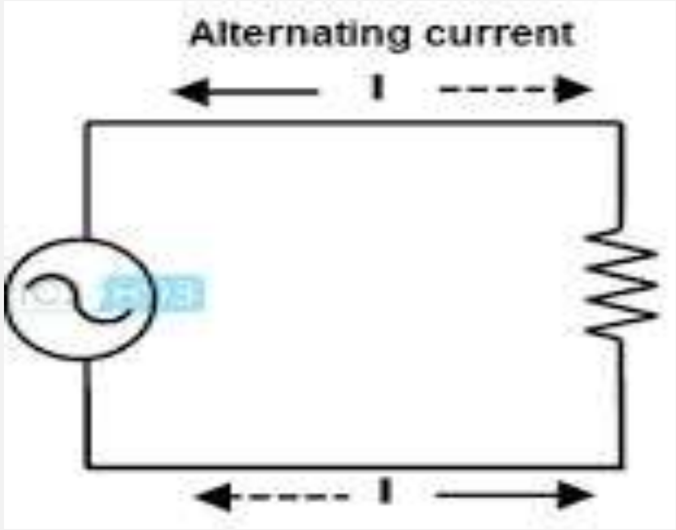
When the electric charge inside the conductor flows in one direction, then such type of current is called direct current. The magnitude of the direct current always remains constant and the frequency of the current is zero. It is used in cell phones, electric vehicles, welding, electronic equipment, etc.

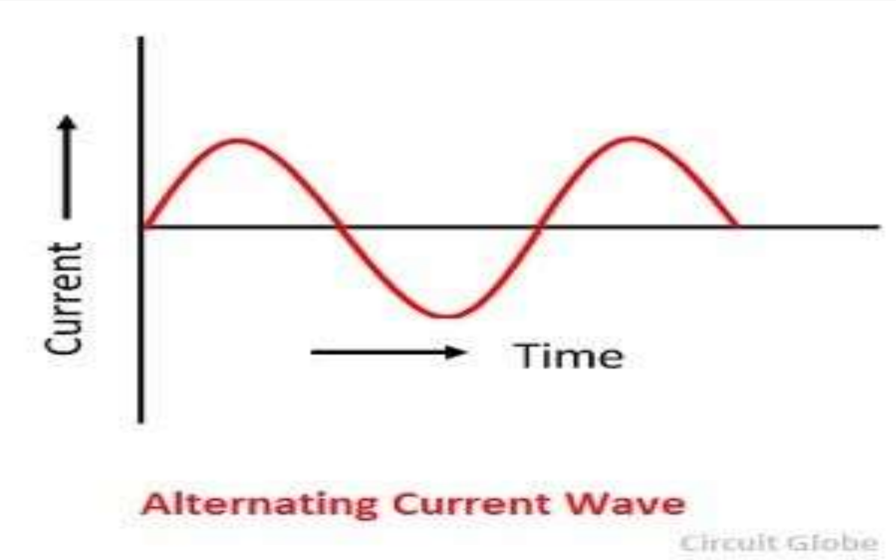




AC (Alternating Current)

The current which changes its directions periodically, such type of current is called alternating current. Their magnitude and polarity also change along with the time. In such types of current, the free electrons (electric charge) moved in the forward as well as in the backwards direction.



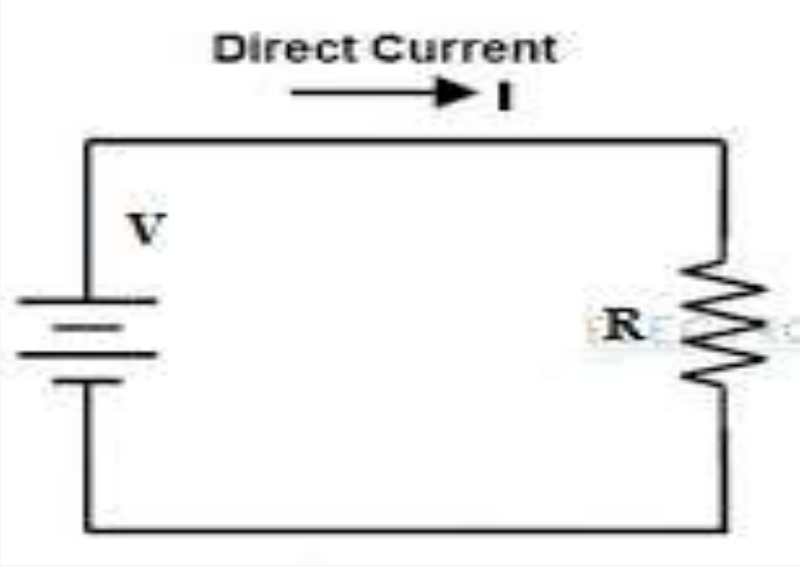


Basis	Alternating current	Direct current
Definition	The direction of the current reverse periodically.	The direction of the current remain same.
Causes of flow of electrons	Rotating a coil in a uniform magnetic field or rotating a uniform magnetic field within a stationary coil	Constant magnetic field across the wire
Frequency	50 or 60 Hertz	Zero
Direction of flow of electrons.	Bidirectional	Unidirectional
Power Factor	Lies between 0 and 1	Always 1
Polarity	It has polarity (+, -)	Do not have polarity
Obtained From	Alternators	Generators, battery, solar cell, etc.
Type of load	Their load is resistive, inductive or capacitive.	Their load is usually resistive in nature.

Graphical Representation	It is represented by irregular waves like triangular wave, square wave, square tooth wave, sine wave.	It is represented by the straight line.
Transmission	Can be transmitted over long distance with some losses.	It can be transmitted over very long distance with negligible losses.
Harazdous	Dangerous	Very dangerous
Application	Factories, Industries and for the domestic purposes.	Electroplating, Electrolysis, Electronic Equipment etc.

DC Circuit

The closed path in which the direct current flows is called the DC circuit. The current flows in only one direction and it is mostly used in low voltage applications. The resistor is the main component of the DC circuit.



Current

Current is the flow of electrical charge carriers like electrons. Current flows from negative to positive points. The SI unit for measuring electric current is the ampere (A). One ampere of current is defined as one coulomb of electrical charge moving past a unique point in a second.
There are two types of electric current, namely alternating and direct current.

$I = V/R$ (Ampere)

$I = dq/dt$ (Ampere)

Voltage

Voltage, potential difference, electric pressure or electric tension is the difference in electric potential between two points, which (in a static electric field) is defined as the work needed per unit of charge to move a test charge between the two points.

A **volt** is the potential difference (voltage) between two points when **1 joule of energy** is used to move **1 coulomb of charge** from one point to the other.

$$V = IR \text{ (Volts)}$$

$$V = Q/C \text{ (Volts)}$$

$$V = W/Q = \text{Joule/ Coulomb(Volts)}$$

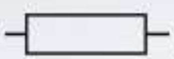
Resistors

Resistor

Three resistors

Type	Passive

Electronic symbol



(Europe)

(US)

Resistance (R) is the physical property of an element that opposes the flow of current . The units of resistance is **Ohms (Ω)**

Resistivity (ρ) is the ability of a material to resist current flow. The units of resistivity is **Ohm-meters (Ω-m)**

Example:

Resistivity of copper	**1.68×10^{-8} Ω·m**
Resistivity of glass	**10^{10} to 10^{14} Ω·m**

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

Ohm's Law

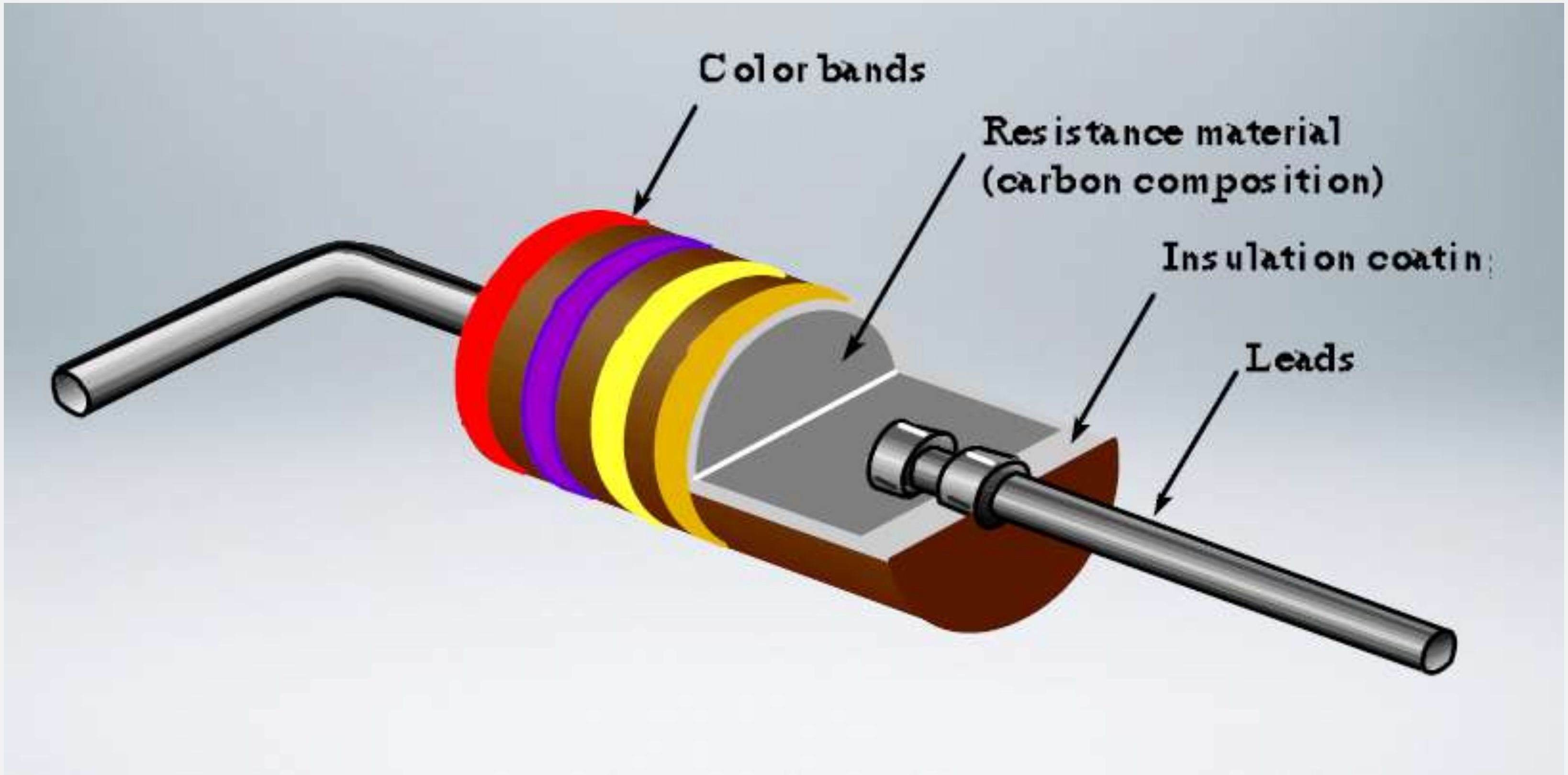
$$\boxed{V = RI}$$

(remember, R is in Ω and ρ is in Ω-m)

$$I = \frac{AV}{\rho L}$$

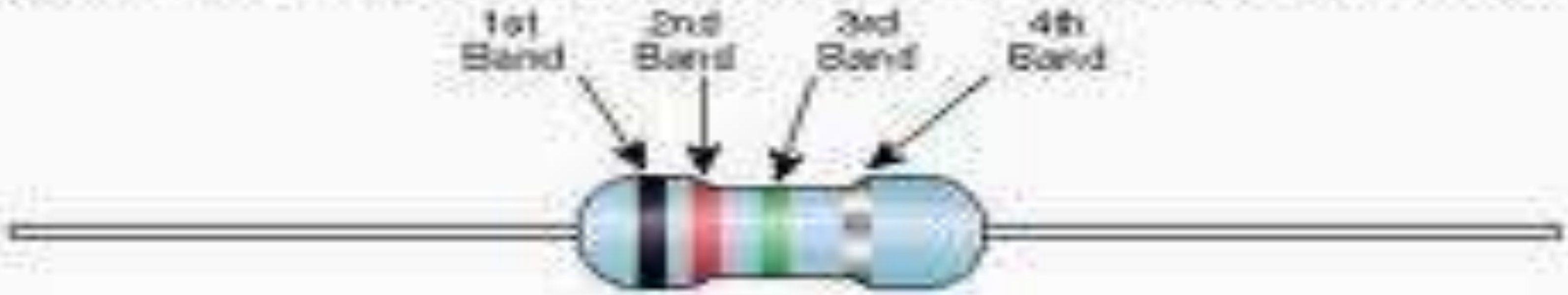
A = Cross-sectional area of wire
L = length of wire

Resistors

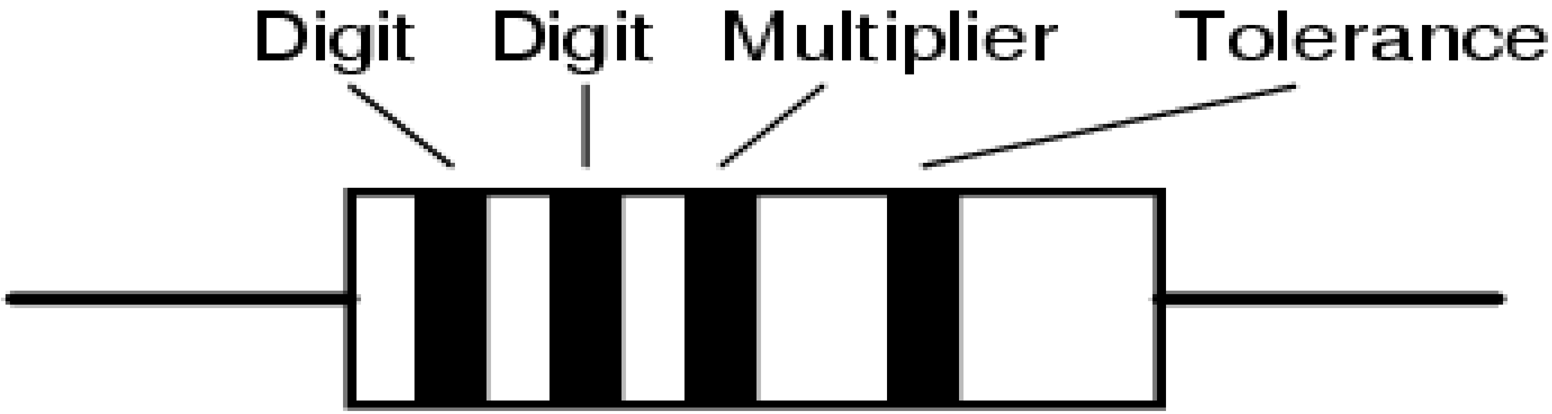

Color bands
Resistance material
(carbon composition)
Insulation coatin
Leads

Resistors

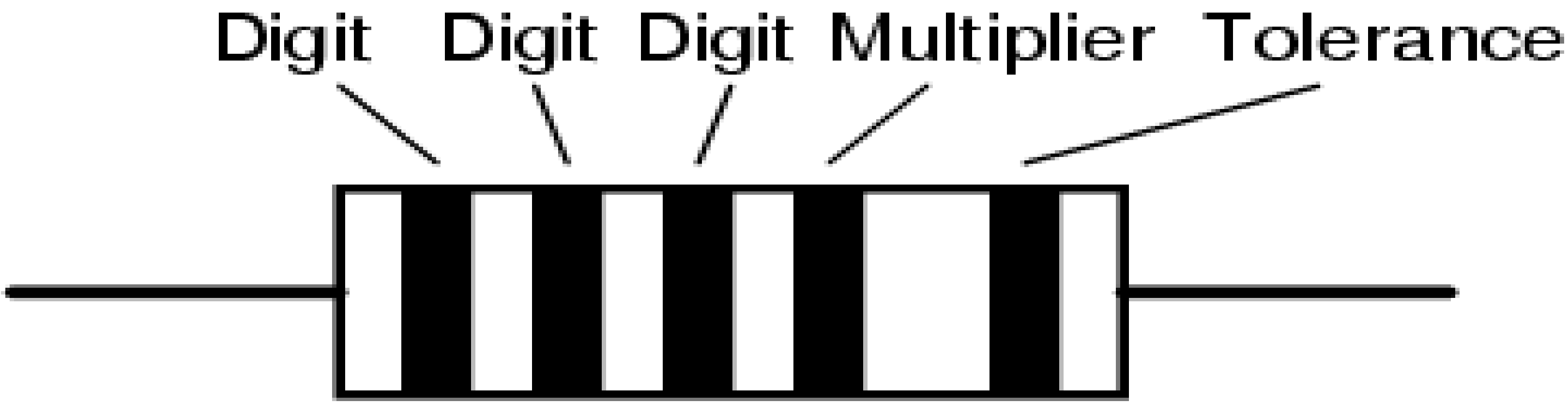
Standard EIA Color Code Table **4 Band:** ±2%, ±5%, and ±10%



Color	1st Band (1st figure)	2nd Band (2nd figure)	3rd Band (multiplier)	4th Band (tolerance)
Black	0	0	10^0	
Brown	1	1	10^1	
Red	2	2	10^2	±2%
Orange	3	3	10^3	
Yellow	4	4	10^4	
Green	5	5	10^5	
Blue	6	6	10^6	
Violet	7	7	10^7	
Gray	8	8	10^8	
White	9	9	10^9	
Gold			10^{-1}	±5%
Silver			10^{-2}	±10%

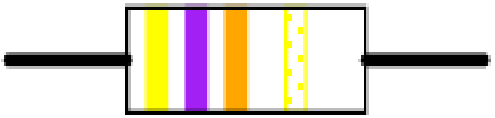


4-band code



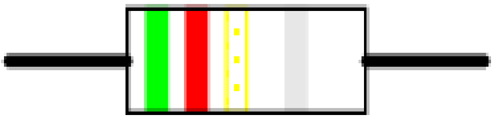
5-band code

Yellow-Violet-Orange-Gold Color Code



A resistor colored *Yellow-Violet-Orange-Gold* would be 47 kΩ with a tolerance of +/- 5%.

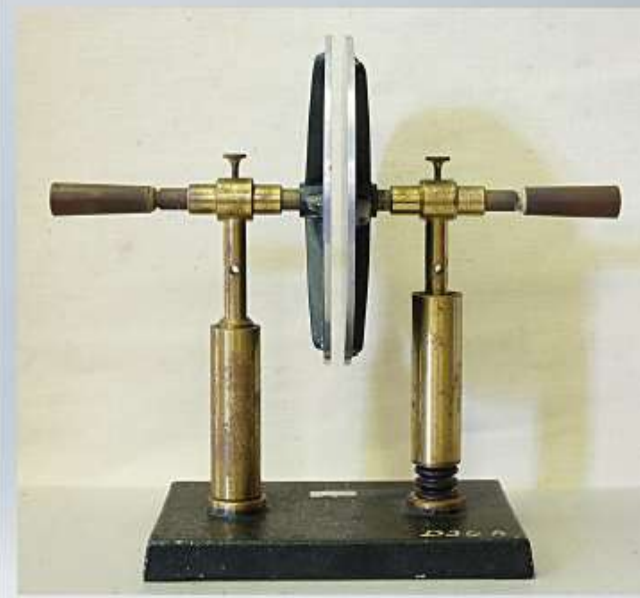
Green-Red-Gold-Silver Color Code



A resistor colored *Green-Red-Gold-Silver* would be 5.2 Ω with a tolerance of +/- 10%.

Capacitors

Capacitor	
 Modern capacitors, by a cm rule	
Type	Passive
Invented	Ewald Georg von Kleist (October 1745)
Electronic symbol	
	



A simple demonstration of a parallel-plate capacitor

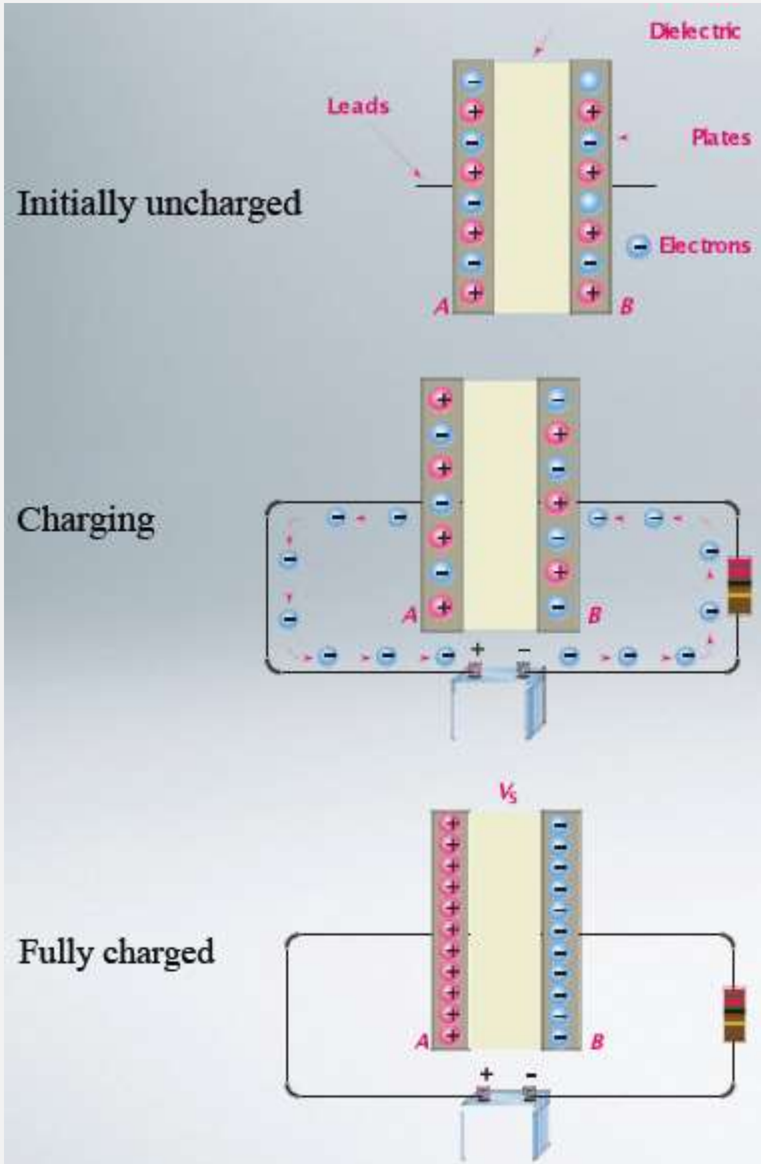
Capacitors

Capacitance (C) *is the ability of a material to store charge in the form of* ***separated charge or an electric field****. It is the ratio of charge stored to voltage difference between two plates.*

$$C = \frac{Q}{V} = \frac{Coloumb}{Volt} = Farad$$

Capacitance is measured in **Farads (F)**

Capacitors



A ***capacitor*** *consists of a pair of conductors separated by a dielectric (insulator).*

$$C = \frac{\epsilon A}{d} \qquad \begin{aligned} \epsilon &= permitivity \\ A &= area \\ d &= distance \end{aligned}$$

(ε indicates how penetrable a subtance is to an electric field)

Electric charge is stored in the plates – a capacitor can become “charged”

When a voltage exists across the conductors, it provides the energy to move the charge from the positive plate to the other plate.

Inductors

Inductor

A selection of low-value inductors

Type	Passive
Working principle	Electromagnetic induction
First production	Michael Faraday (1831)

Electronic symbol

An **inductor** is a two terminal element consisting of a winding of N turns capable of **storing energy in the form of a magnetic field**

Inductance (L) is a measure of the ability of a device to store energy in the form of a **magnetic field**. It is measured in **Henries (H)**

Inductors

Inductance in a cylindrical coil

$$L = \frac{\mu_0 K N^2 A}{l}$$

μ_0 = permeability of free space = $4\pi \times 10^{-7}$ H/m

K = Nagaoka coefficient

N = number of turns

A = area of cross-section of the coil in m^2

l = length of coil in m

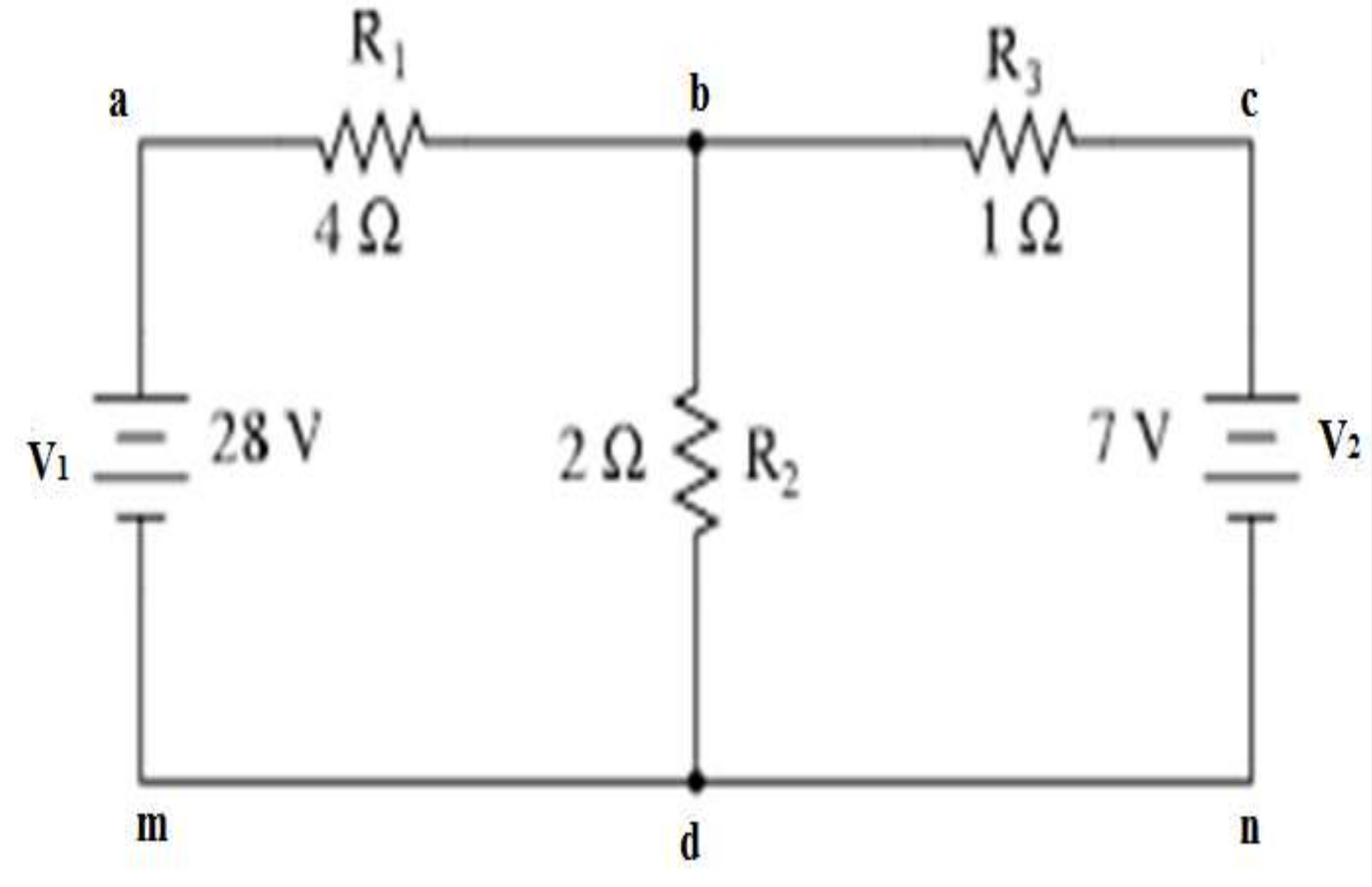
The magnetic field from an inductor can generate an induced voltage, which can be used to drive current

$$v = L\frac{di}{dt}$$

Terminologies

1. **Active Element:** The element which supplies energy to the circuit is called active element, such as voltage sources, current source, batteries.
2. **Passive Element:** The element which receives energy is called passive element, such as resistor, inductor & capacitor.
3. **Node:** It is the point in the network where two or more circuit elements are joined.
4. **Junction:** It is the point in the network where three or more circuit elements are joined.
5. **Branch:** The part of a network which lies between two junction point is called branch.

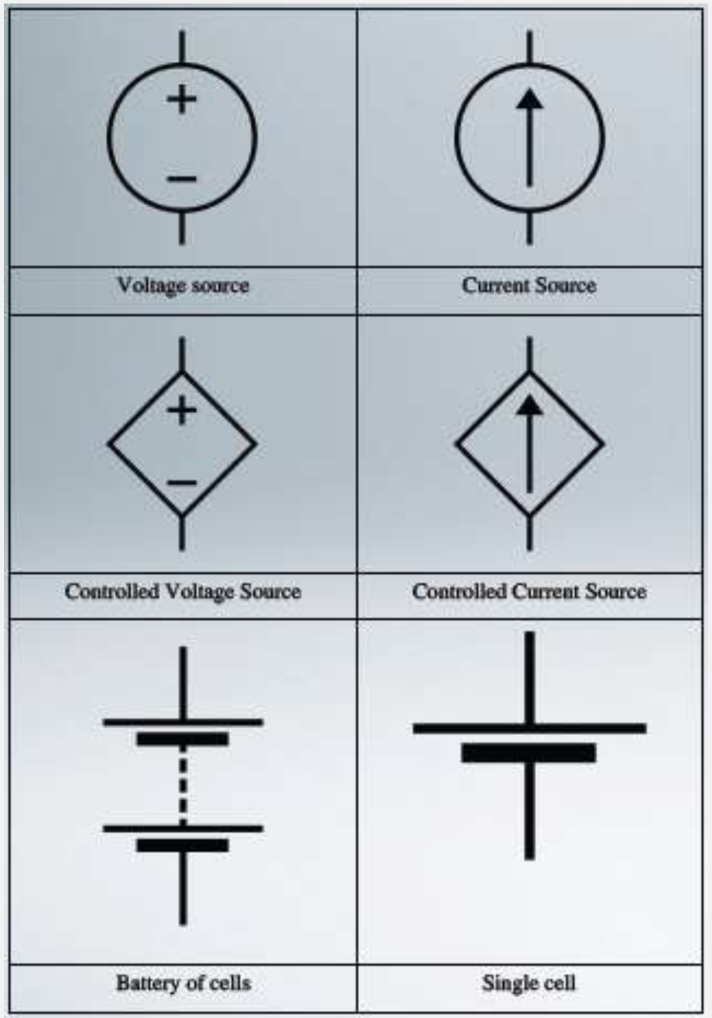
6. **Loop:** The closed path of the network is called loop.
7. **Mesh:** The most elementary form of a loop which cannot be further divided is called mesh.
8. **Uilateral Element:** The element which allows current to flow only in one direction, such as diode, thyristor, SCR, etc.
9. **Bilateral Element:** The element which allows current to flow in both direction., such as resistor, capacitor, inductor, etc.



R1
a
b
R3
c
4 Ω
1 Ω
V1
28 V
2 Ω
R2
7 V
V2
m
d
n

1. Active Elements	(R_1, R_2 & R_3)
2. Passive Elements	(V_1 & V_2)
3. Node	(a, b, c & d)
4. Junction	(b & d)
5. Branch	(bamd, bcnd & bd)
6. Loop	(abda, bcdb & abcda)
7. Mesh	(abda & bcdb)
8. Unilateral Elements	
9. Bilateral Elements	

Electrical sources



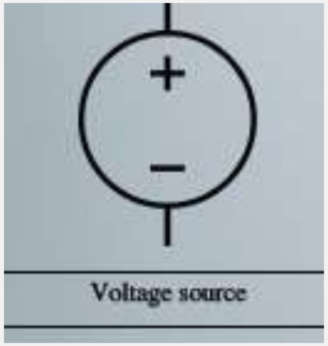
An **electrical source** is a **voltage** or **current generator** capable of supplying energy to a circuit

Examples:

-AA batteries
-12-Volt car battery
-Wall plug

Ideal voltage source

An **ideal voltage source** is a circuit element where the **voltage across the source is independent of the current through it**.



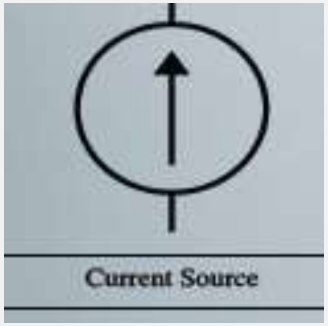
V=IR

The internal resistance of an ideal voltage source is zero.

If the current through an ideal voltage source is completely determined by the external circuit, it is considered an **independent voltage source**

Ideal current source

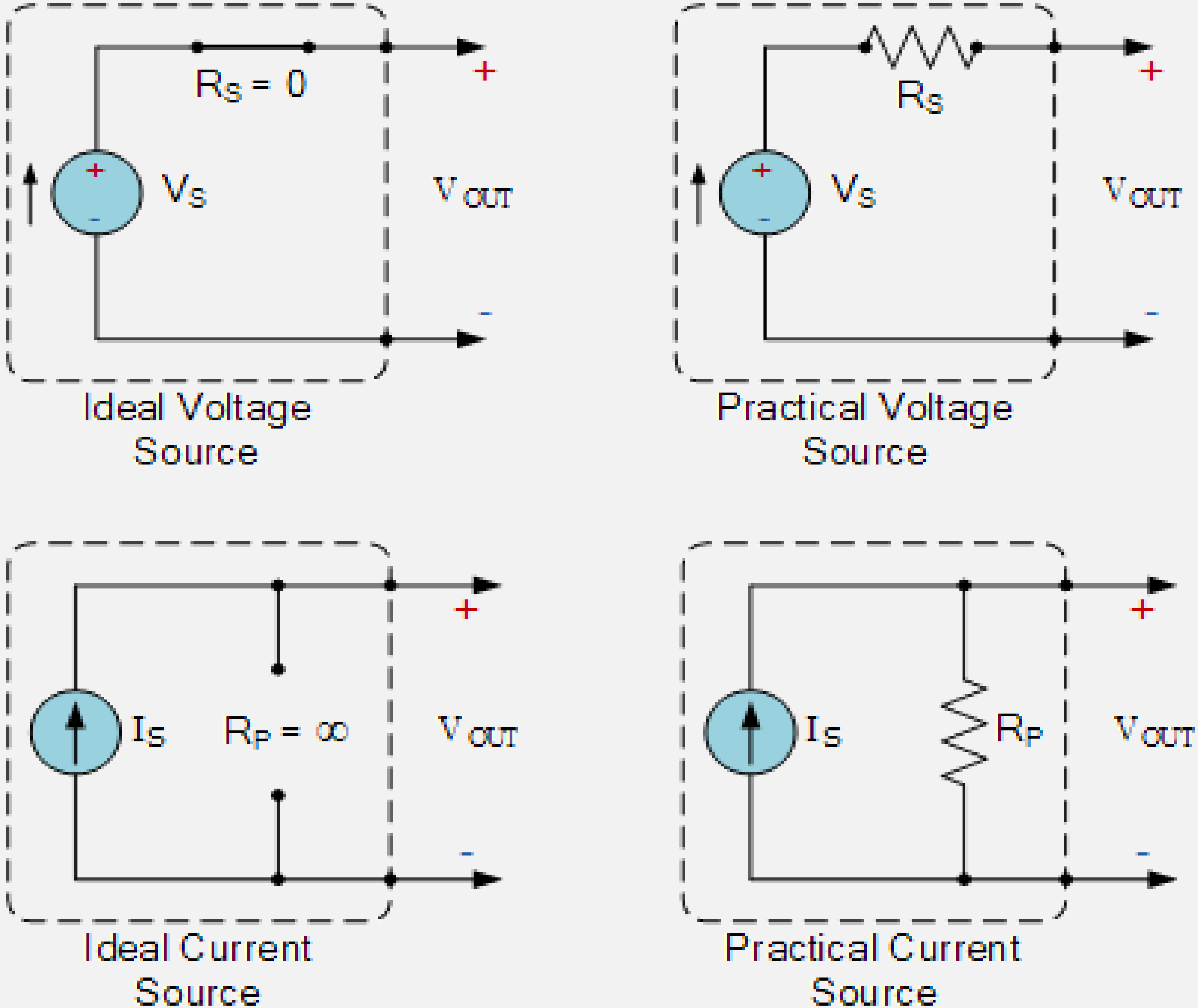
An **ideal current source** is a circuit element where the **current through the source is independent of the voltage across it**.



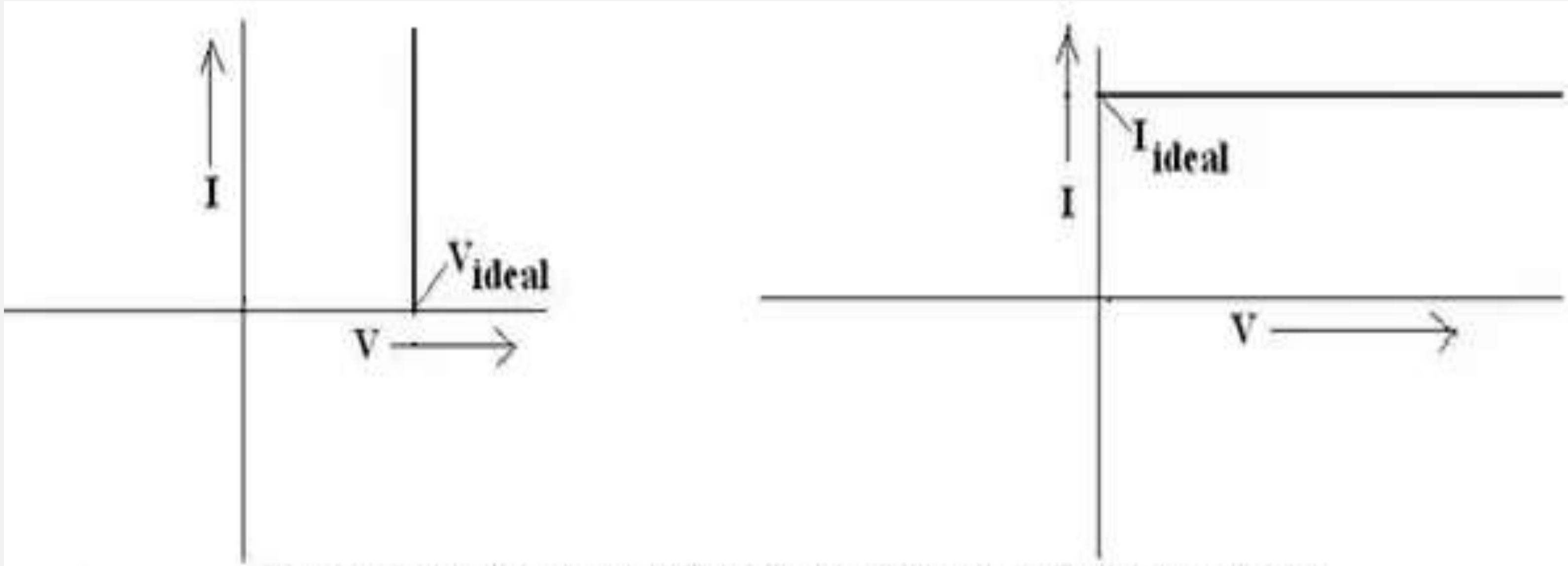
I = V/R

The internal resistance of an ideal current source is infinite.

If the voltage across an **ideal current source** is completely determined by the external circuit, it is considered an **independent current source**



Rs = 0
+
Vs
VOUT
-
Ideal Voltage Source
Rs
+
Vs
VOUT
-
Practical Voltage Source
+
Is
RP = ∞
VOUT
-
Ideal Current Source
+
Is
RP
VOUT
-
Practical Current Source



Ideal Voltage Source and Ideal Current Source I-V characteristics.

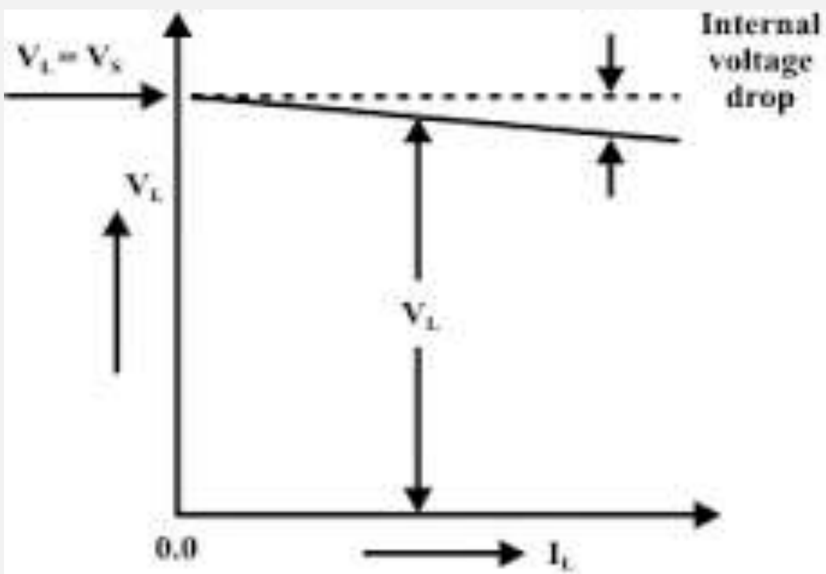
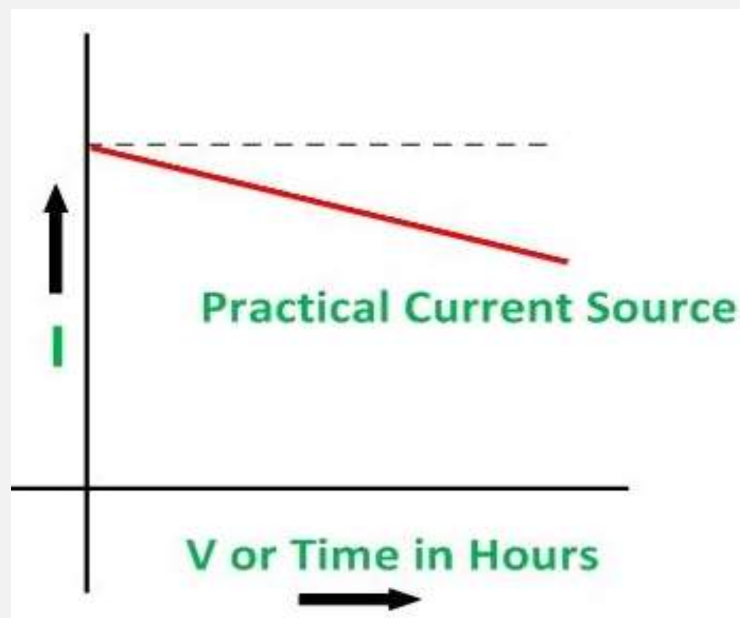
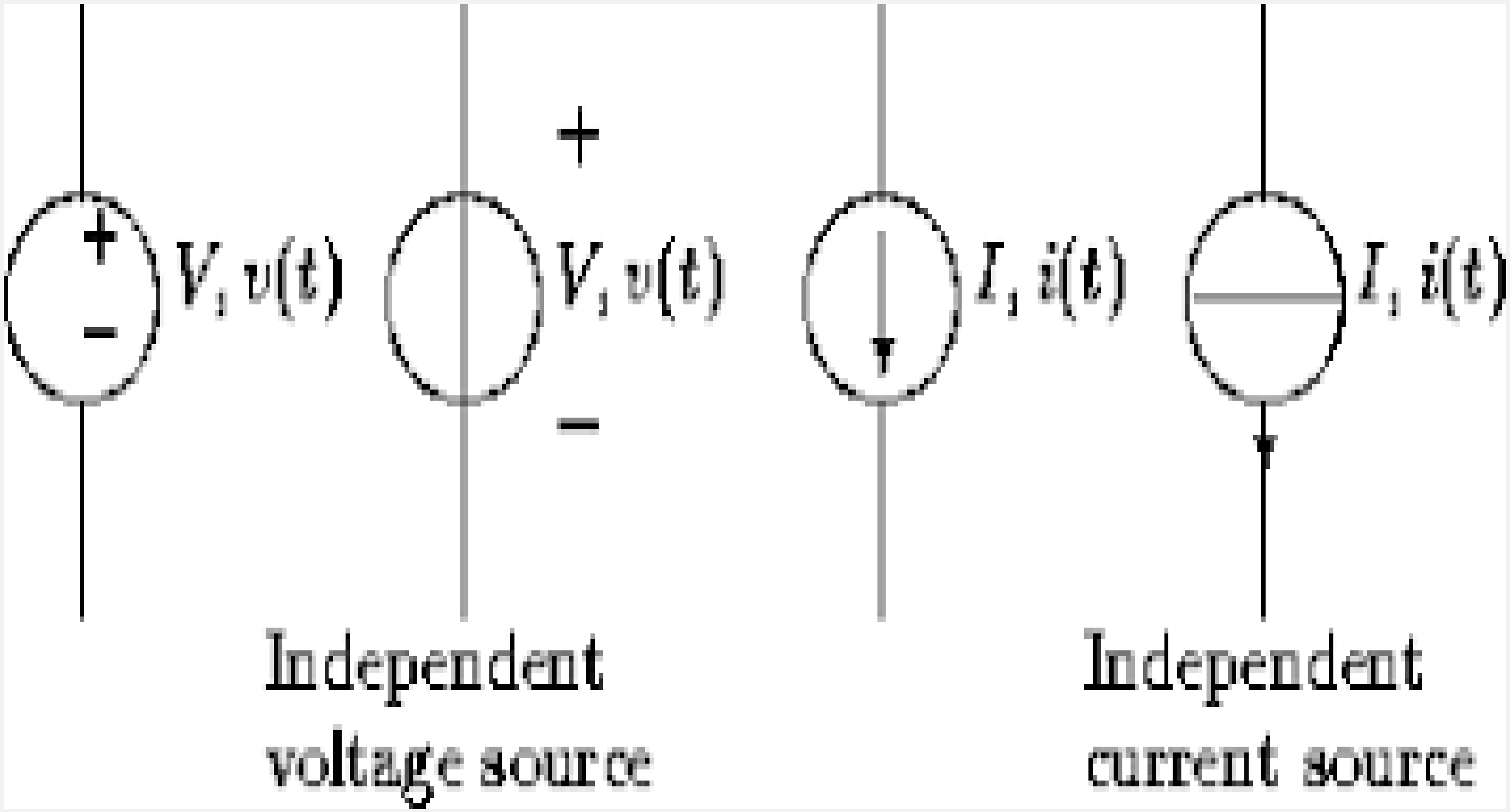


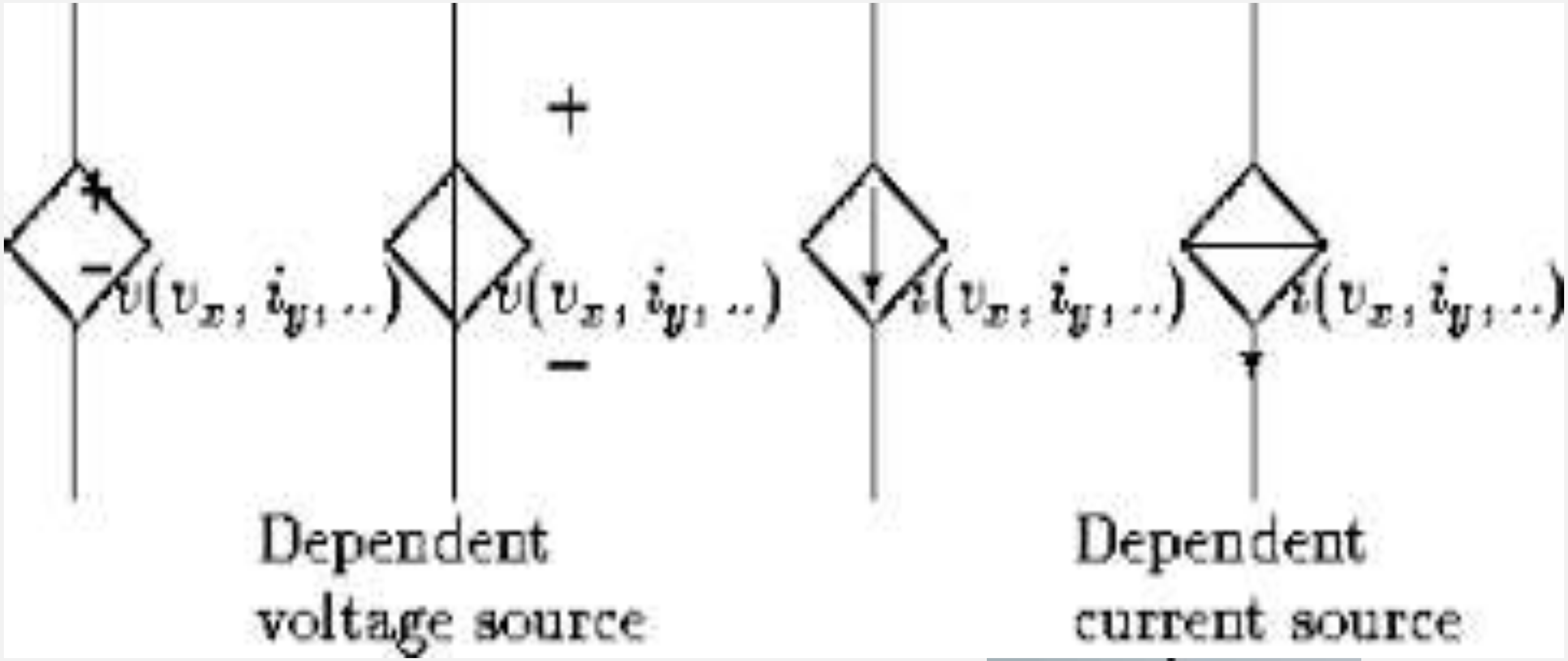
Fig. 3.16: V-I characteristics of practical voltage source

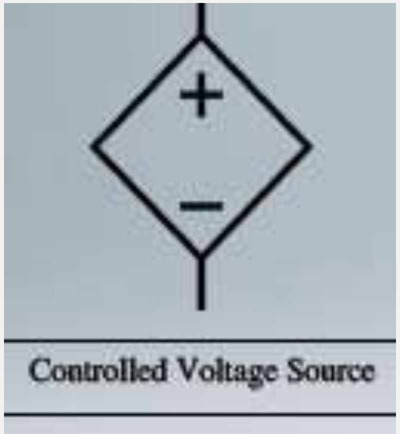


Independent Sources

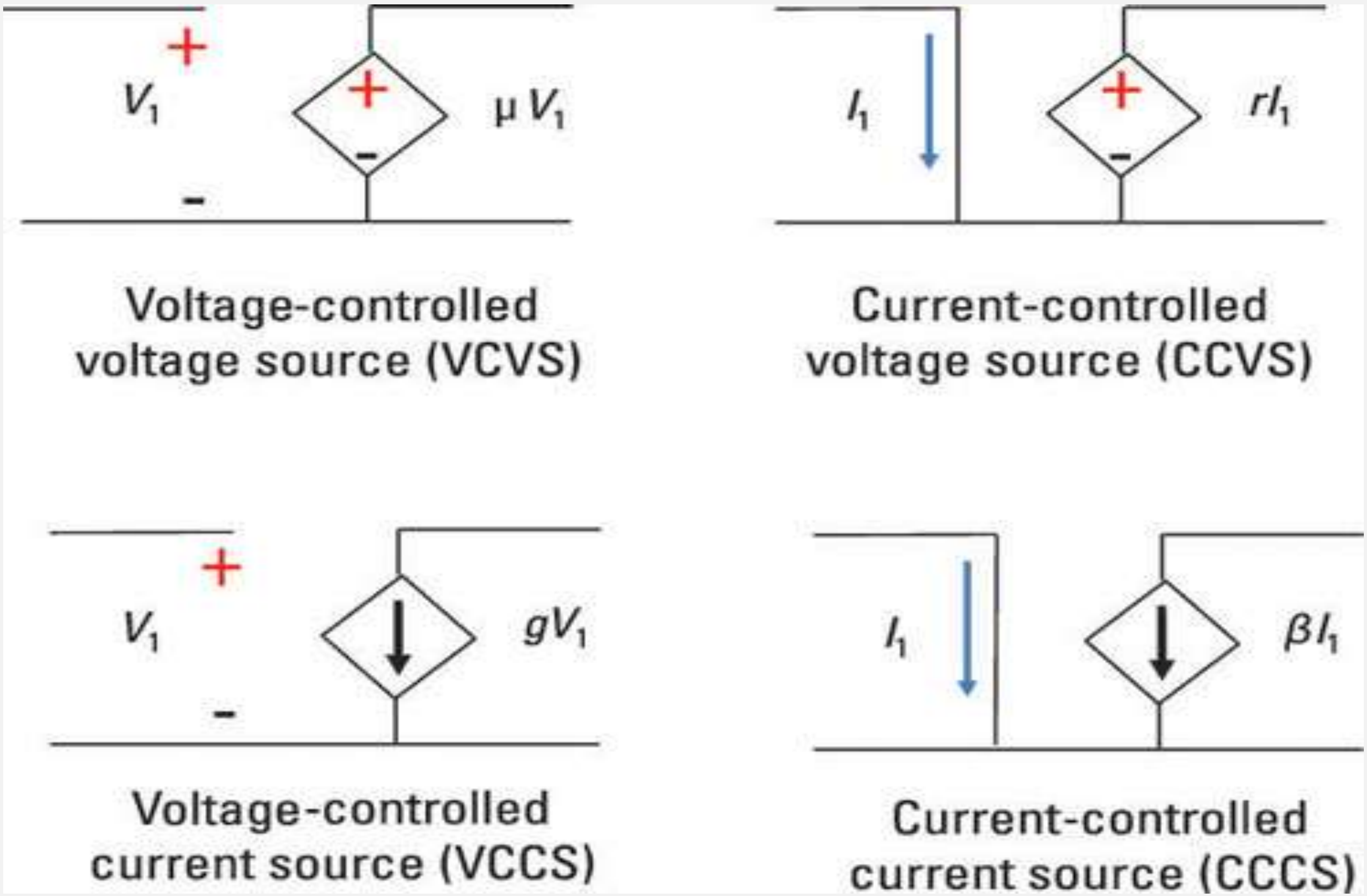


Dependent Sources





Dependent Sources



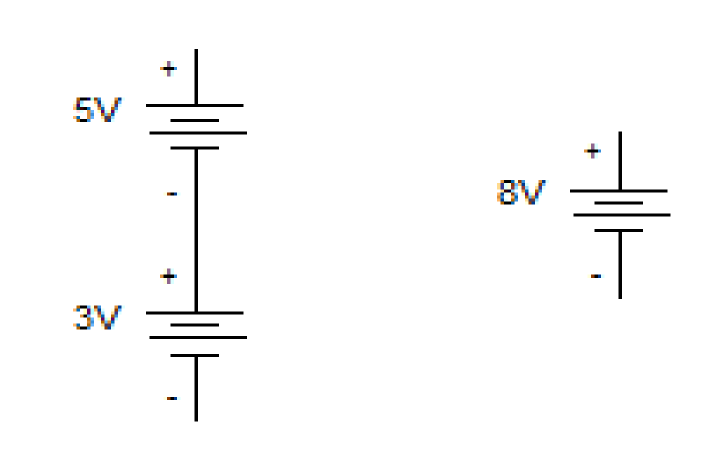
Voltages Sources and Current Sources

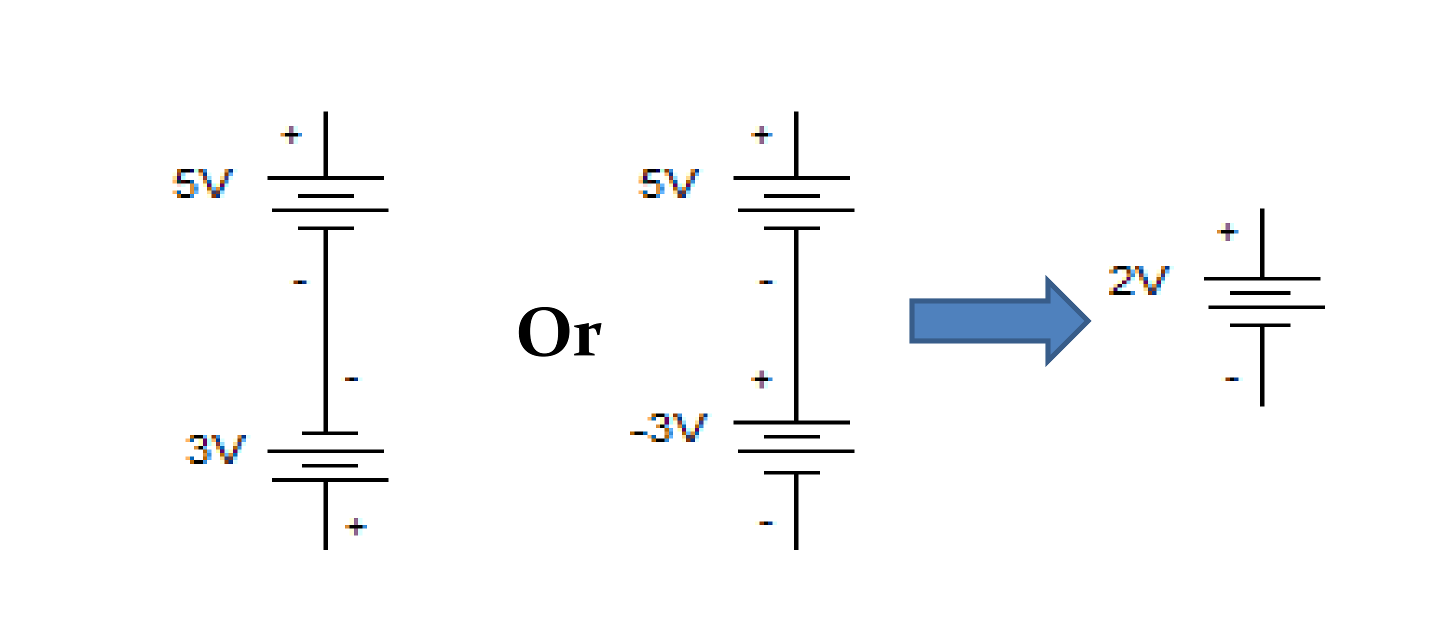
Series and Parallel Combinations

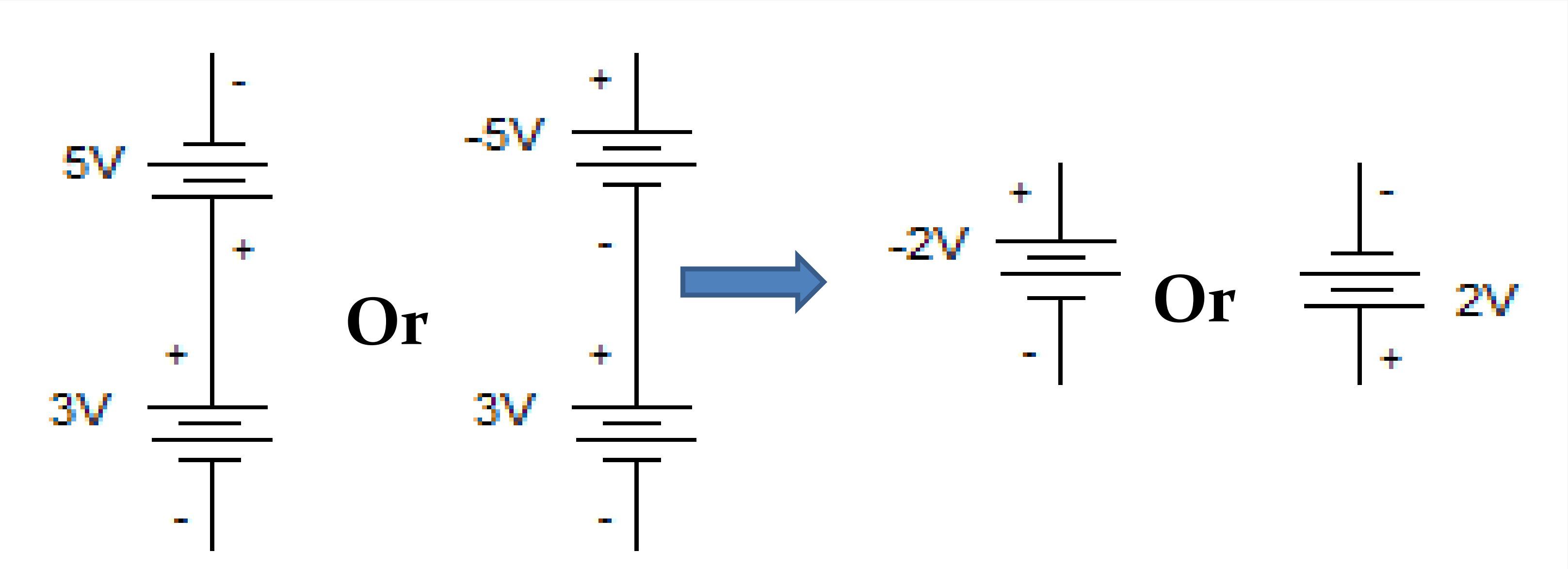
Voltage Sources in Series

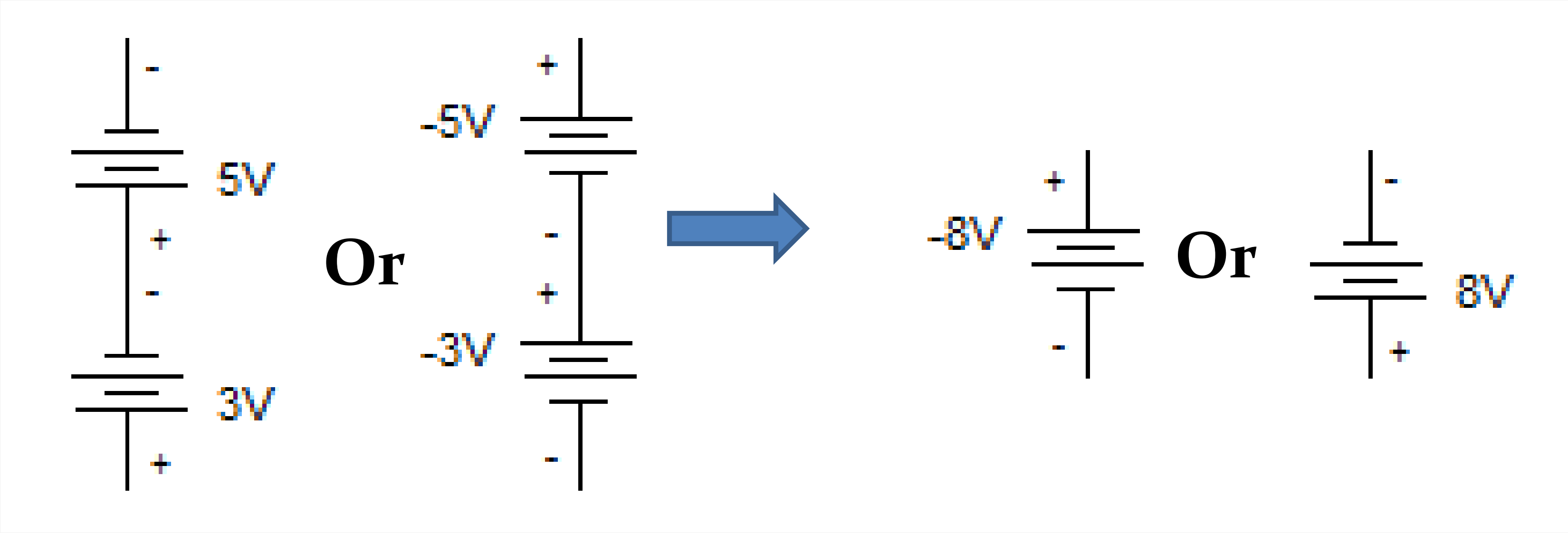
- DC voltage sources in series can be combined and replaced with a single source.
- AC voltage sources in series can be combined and replaced with a single source only if the angular frequency of operation w are identical.
- DC and AC voltage sources can be added together when calculating a total voltage.
- AC voltage sources operating at different frequencies can be added together.
- The current flowing through one voltage source must be equal to the current flowing through the other voltage source.

Examples





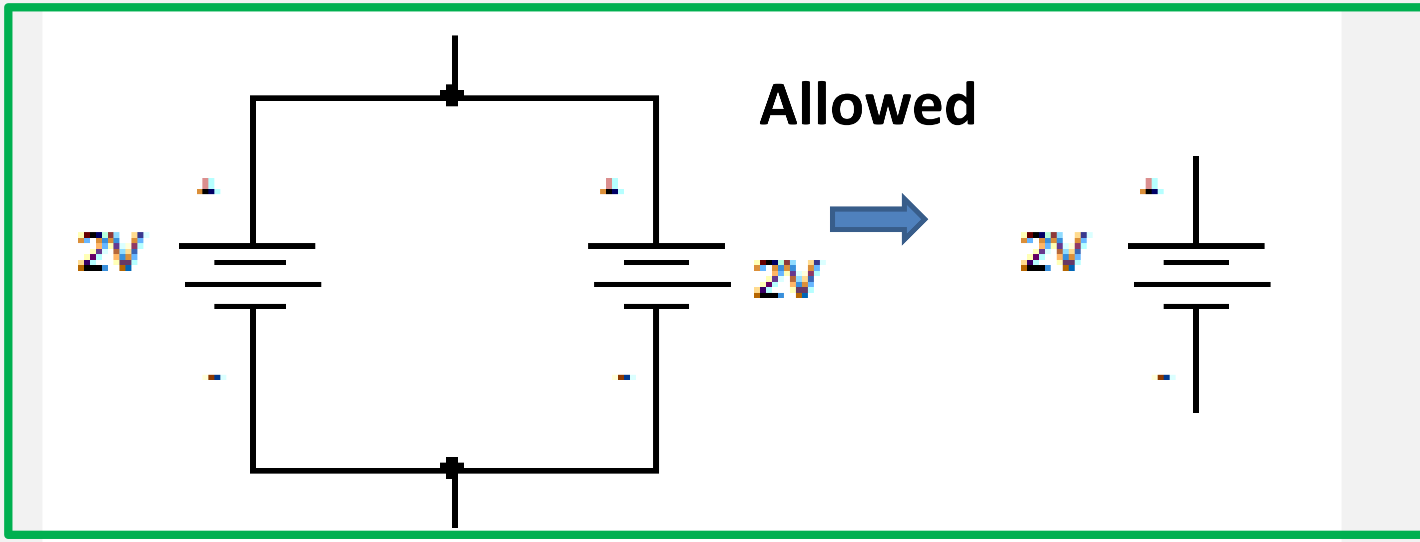

5V
3V
Or
-5V
3V
-2V
Or
2V

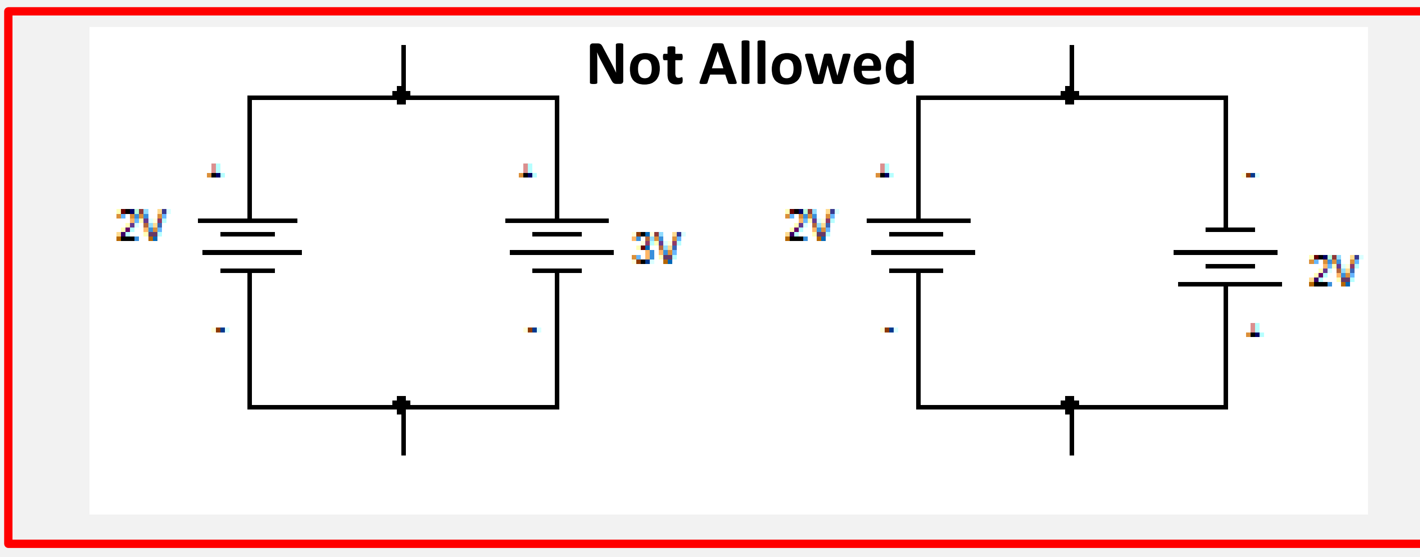

5V
3V
Or
-5V
-3V
-8V
Or
8V

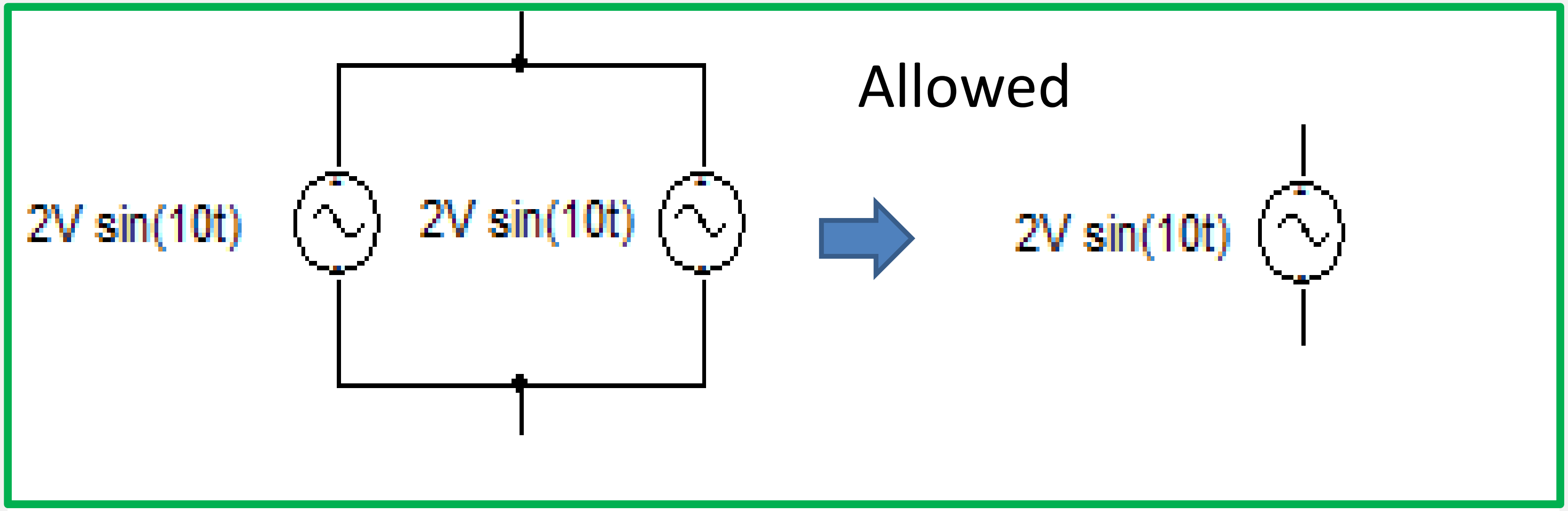
Voltage Sources in Parallel

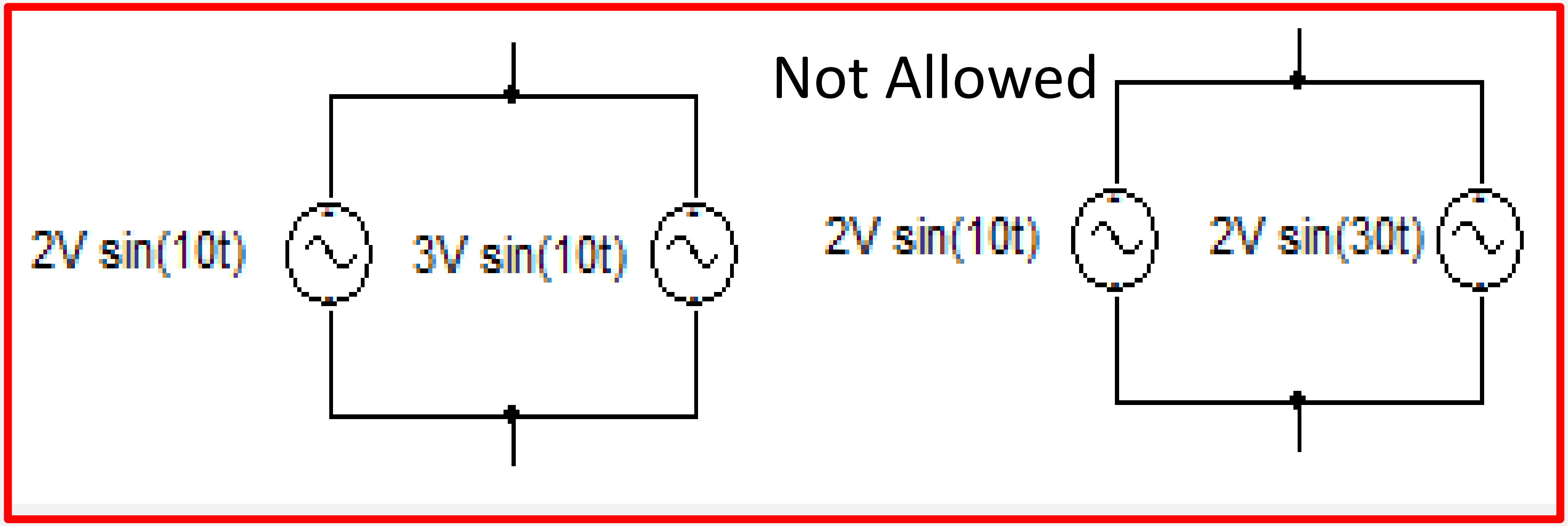
Since the voltage sources share common nodes, the two or more voltage sources are allowed in parallel is only when they have exactly the same voltage, polarity.

–The multiple voltage sources can be replaced by a single source with the same voltage, polarity, and frequency of operation (if ac sources).


Allowed
2V
2V
2V

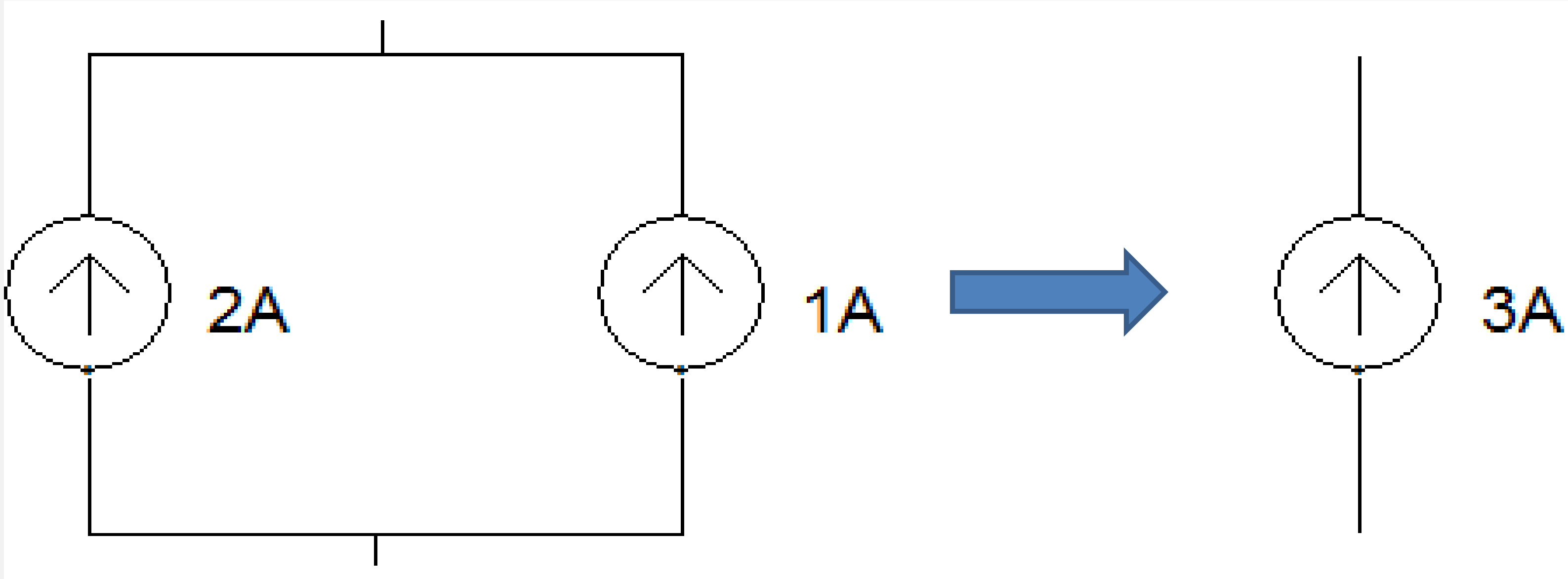

Not Allowed
2V
3V
2V
2V

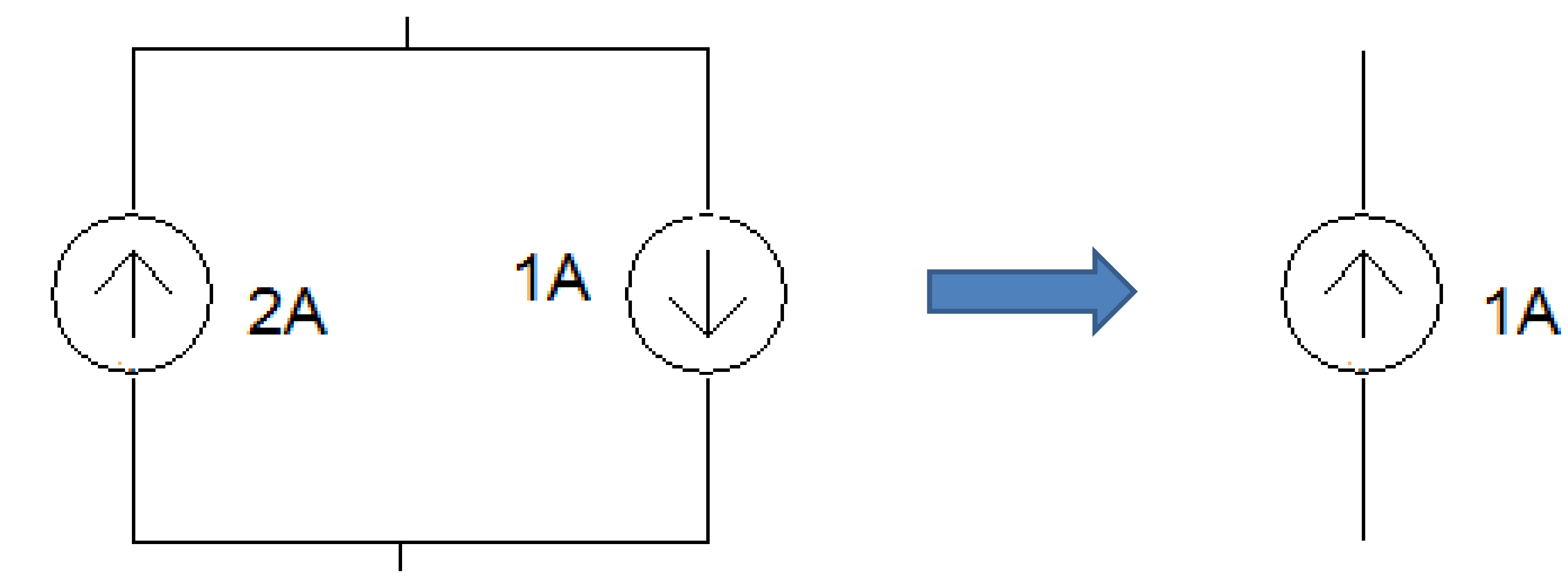

Allowed
2V sin(10t)
2V sin(10t)
2V sin(10t)

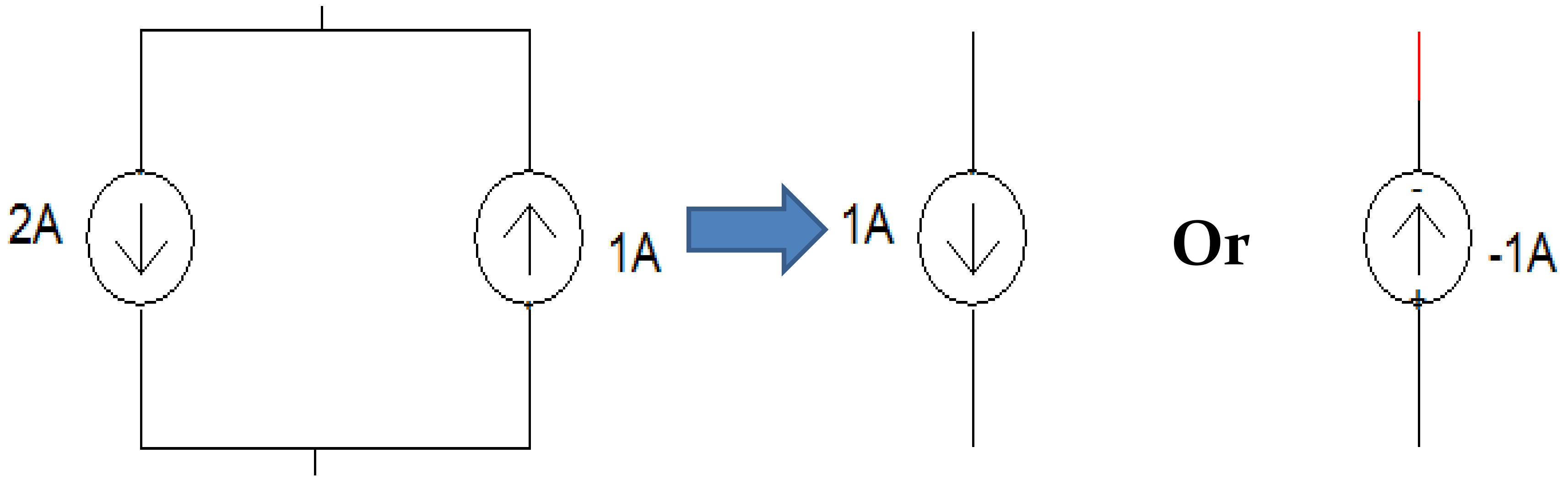

Not Allowed
2V sin(10t)
3V sin(10t)
2V sin(10t)
2V sin(30t)

Current Sources in Parallel

- DC current sources in parallel can be combined and replaced with a single source.
- AC current sources in parallel can be combined and replaced with a single source only if the angular frequency of operation ω are identical.
- DC and AC current sources in parallel can be added together when calculating a total current.
- AC current sources operating at different frequencies can be added together.
- The voltage drop across one current source must be equal to the voltage dropped across the other current sources in parallel.


2A
1A
3A


2A
1A
1A

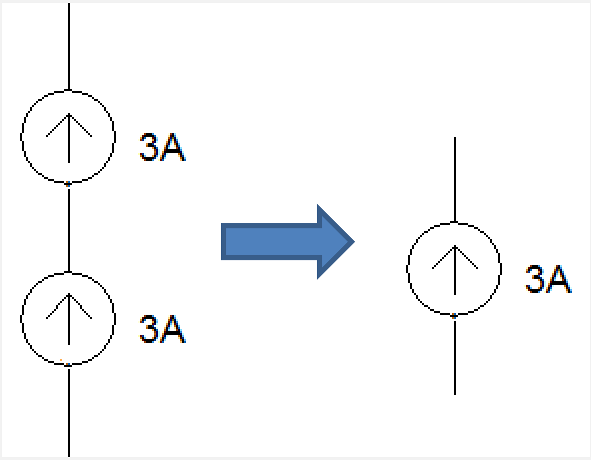

2A
1A
1A
Or
-1A
-
+

Current Sources in Series

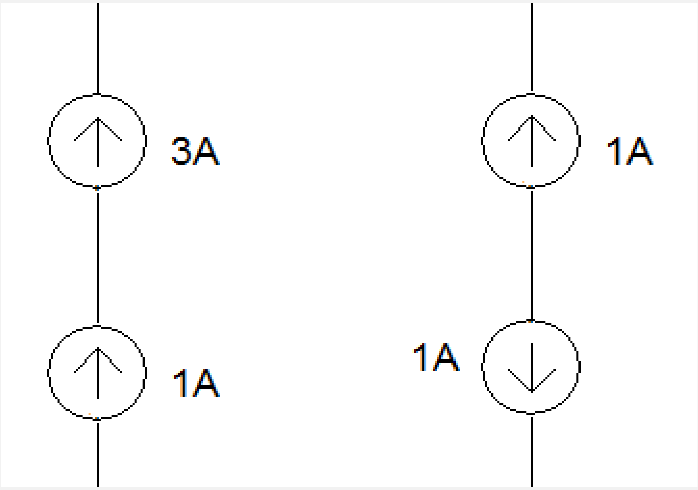
Since components in series must have the same current flowing through each component. Two or more currents sources are allowed in series only when they have exactly the same magnitude of current, the current is flowing in the same direction, and frequency of operation (if ac sources).

–The multiple current sources in series can be replaced by a single source with the same magnitude, direction of current flow, and frequency of operation (if ac sources).

Allowed



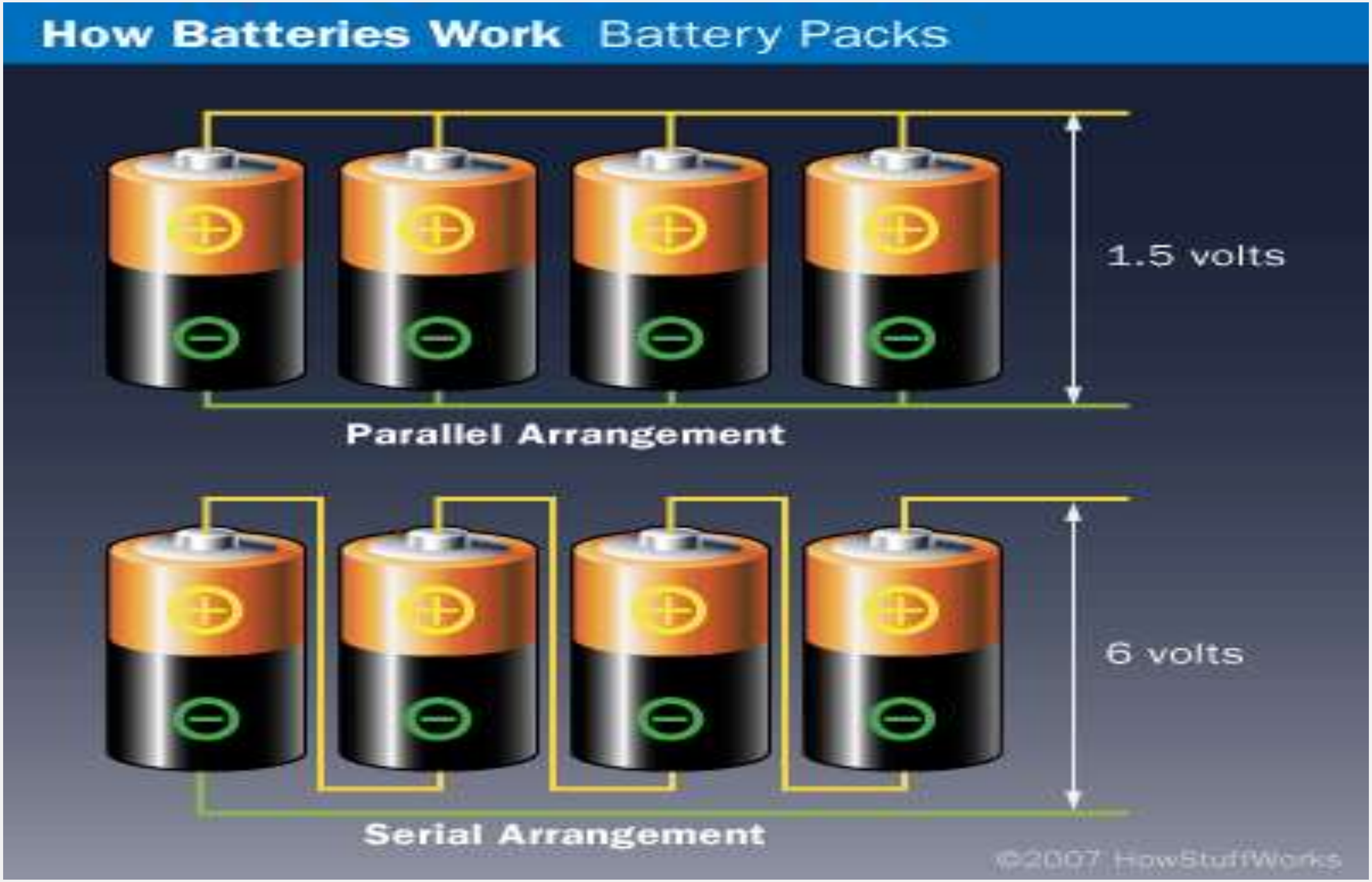
Not Allowed



Summary

- Voltage sources in series can be added.
- Current sources in parallel can be added.
- Only in the case where the magnitude, polarity, and frequency of operation are identical can multiple voltage sources be connected in parallel.
- They can be replaced with a single voltage source of the same magnitude, polarity, and frequency of operation.
- Only in the case where the magnitude, direction of current flow, and frequency of operation are identical can multiple currents sources be connected in series.
- They can be replaced with a single current source of the same magnitude, direction of current flow, and frequency of operation.

Batteries in Series and Parallel



Circuit diagrams

- **Minimum Three elements:**

  -Source of electricity (battery)

  -Path or conductor on which electricity flows (wire)

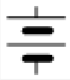
  -Electrical resistor (lamp) which is any device that requires electricity to operate
- **Pictorial way of showing circuits**

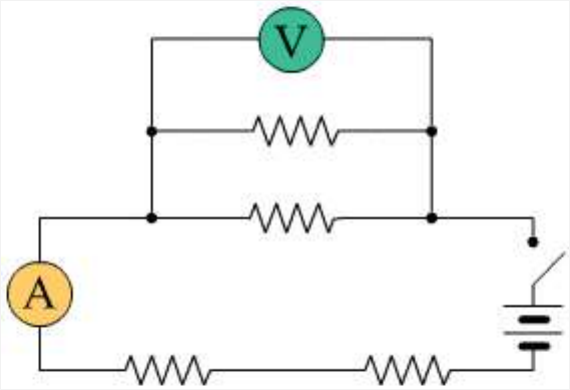
This is the Ammeter symbol

This is the Voltmeter symbol.


This is the resistor symbol.


This is the switch symbol.

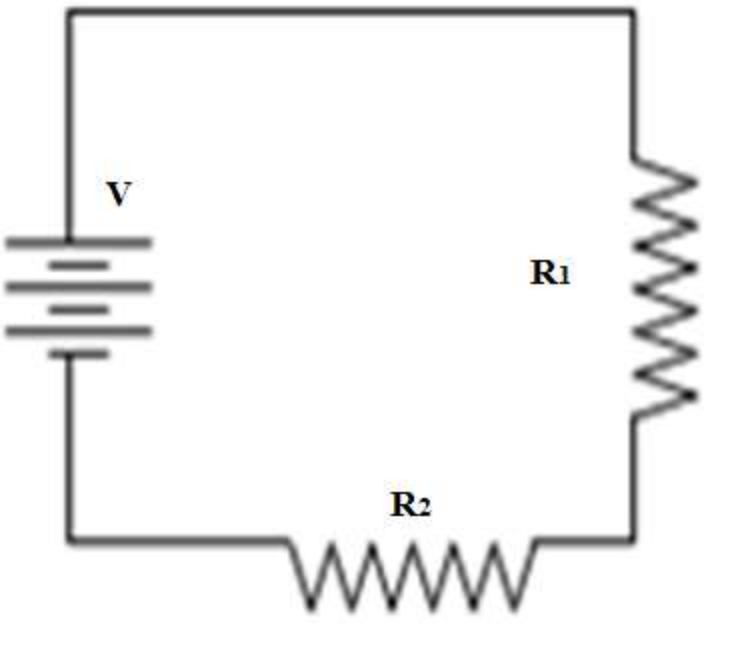

This is the battery symbol.



Resistors in Series & Parallel

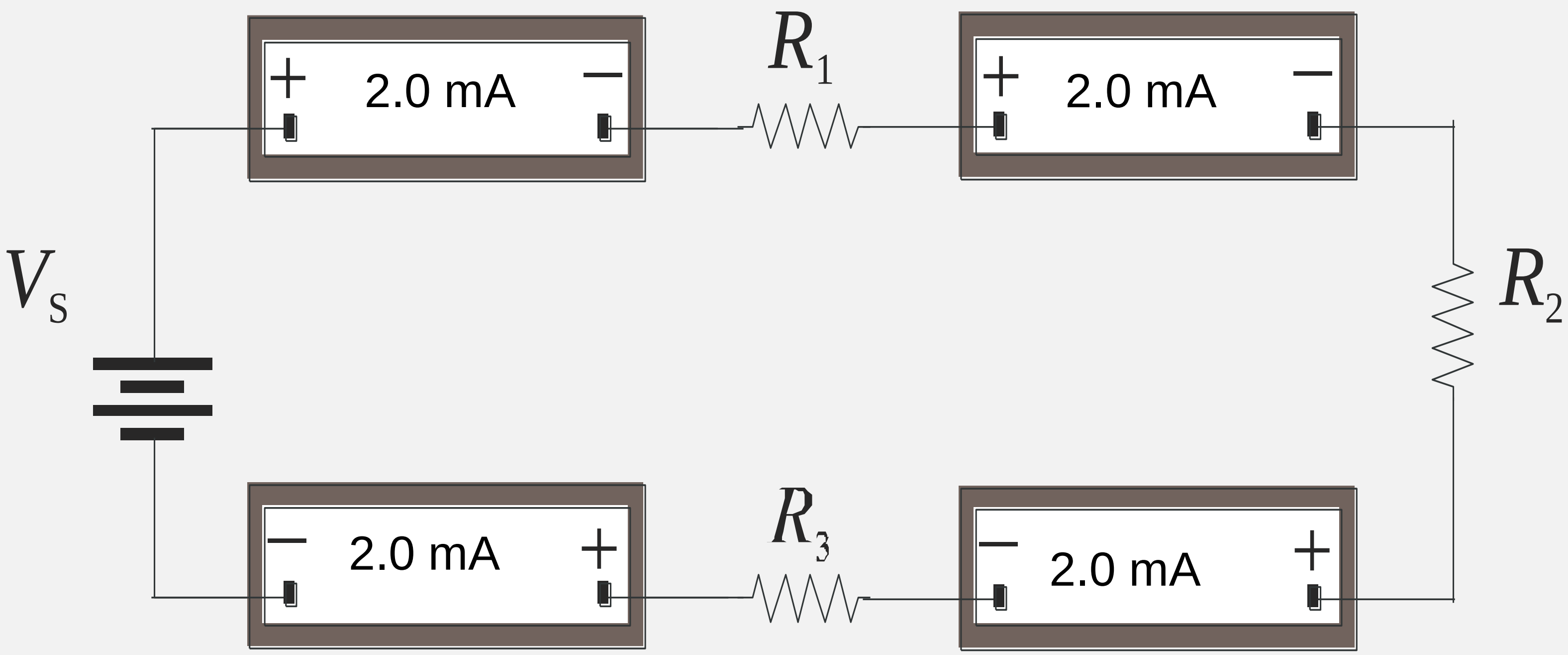
Resistance in Series

- Series circuit - has only one path through which the electricity can flow.
- When two circuit elements connect at single point
- In the above diagram, the electricity flows through both loads.
- In series circuit current will remain same.

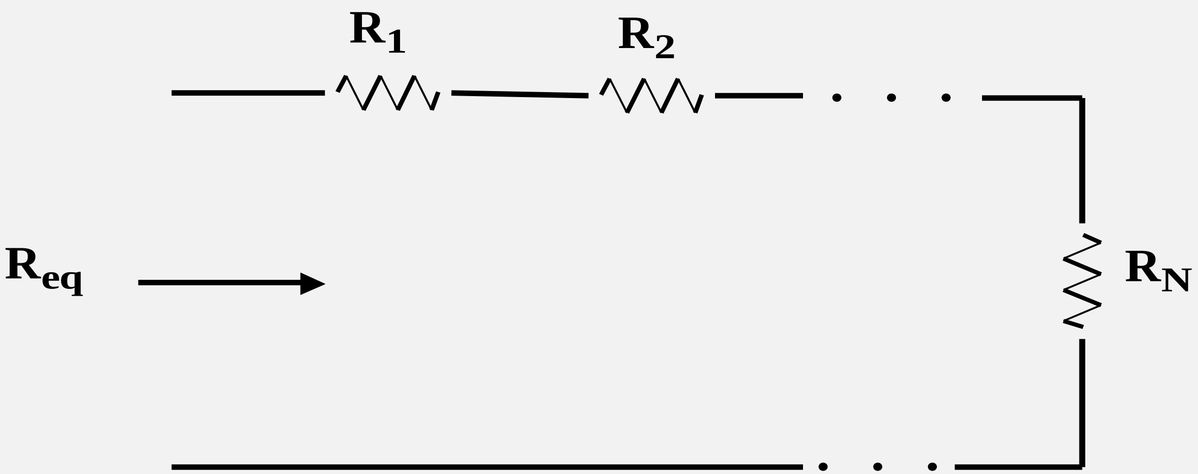


Series circuit rule for current

Because there is only one path, the current in each resistor will be same



Series Equivalent Resistance:



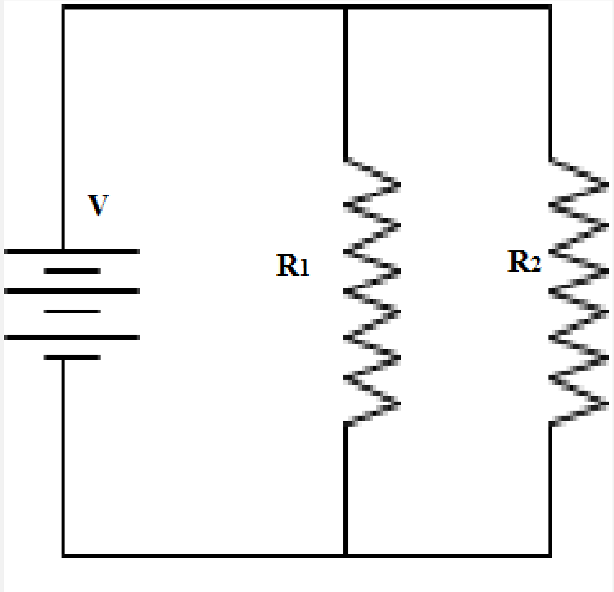
Resistors in series.

$$R_{eq} = R_1 + R_2 + \ldots + R_N$$

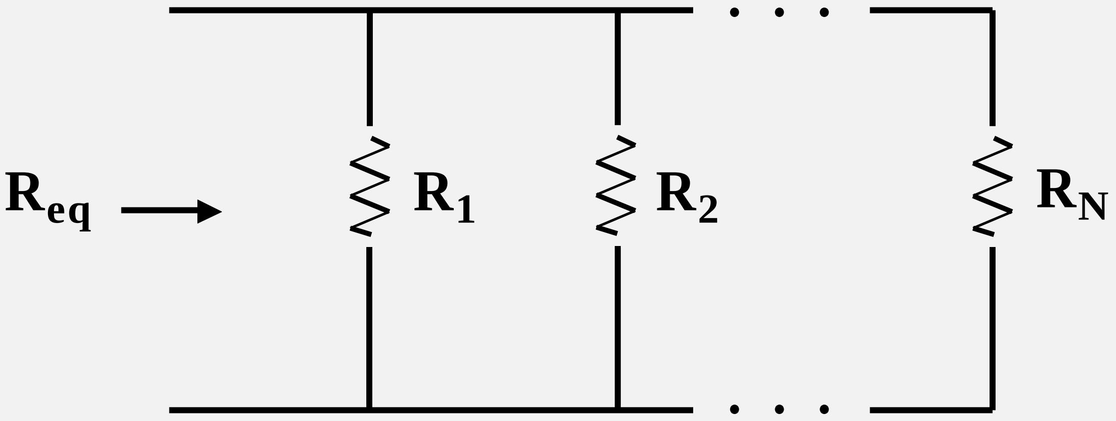
For the case of series circuit equivalent resistance is larger than largest resistance in a series connection.

Parallel Circuit

- Parallel circuit -When two circuit elements connect at single Node pair.
- In parallel circuit voltage will remain same across their terminals.
- A **parallel circuit** has multiple paths through which the electricity can flow.
- In a parallel circuit, the current though one path may be different than the current through the other path.



Equivalent Resistance:



Resistors in parallel.

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

Equivalent Resistance:

For the special case of two resistors in parallel:

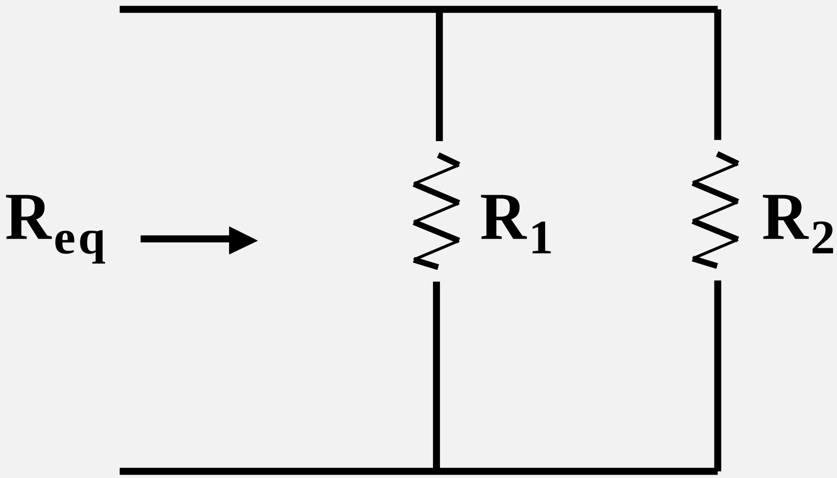


Figure: Two resistors in parallel.

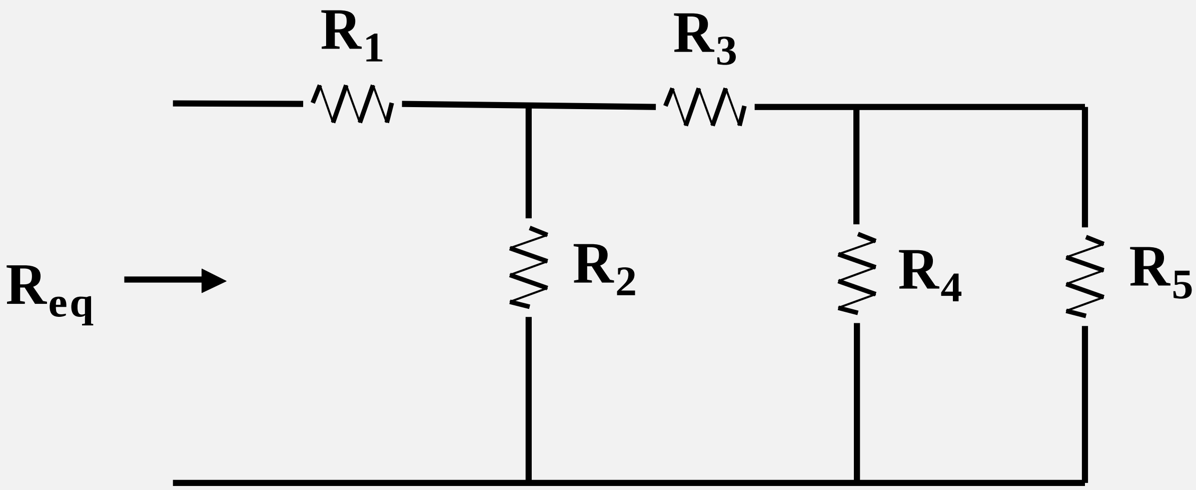
$$1 \backslash R_{eq} = \frac{R_1 + R_2}{R_1 R_2}$$

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

Equivalent Resistance:

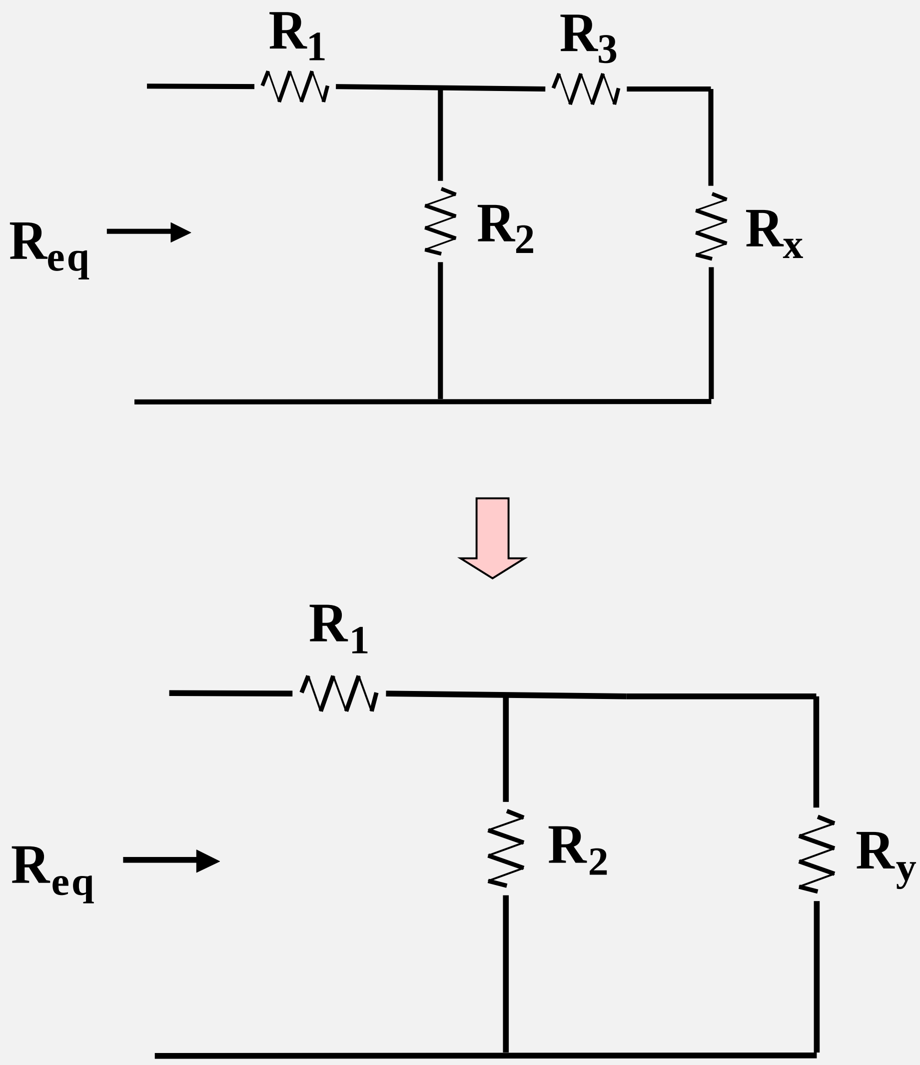
Series – Parallel Combination

By combination we mean we have a mix of series and Parallel. This is illustrated below.



Resistors In Series – Parallel Combination

To find the equivalent resistance we usually start at the output of the circuit and work back to the input.

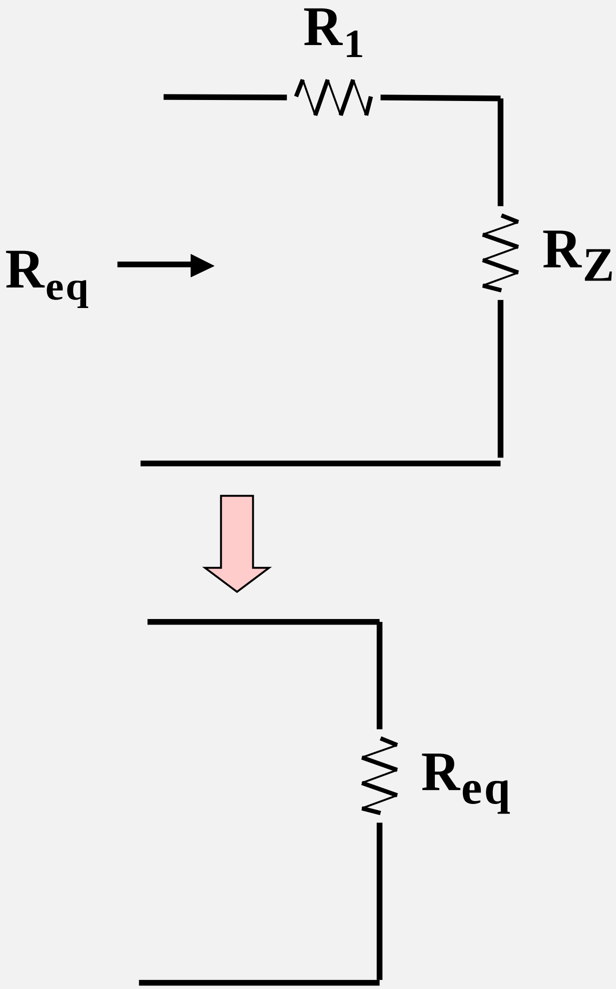


$$R_x = \frac{R_4 R_5}{R_4 + R_5}$$

$$R_y = R_x + R_3$$

Resistance reduction.

<u>Equivalent Resistance:</u> **Resistors in combination.**

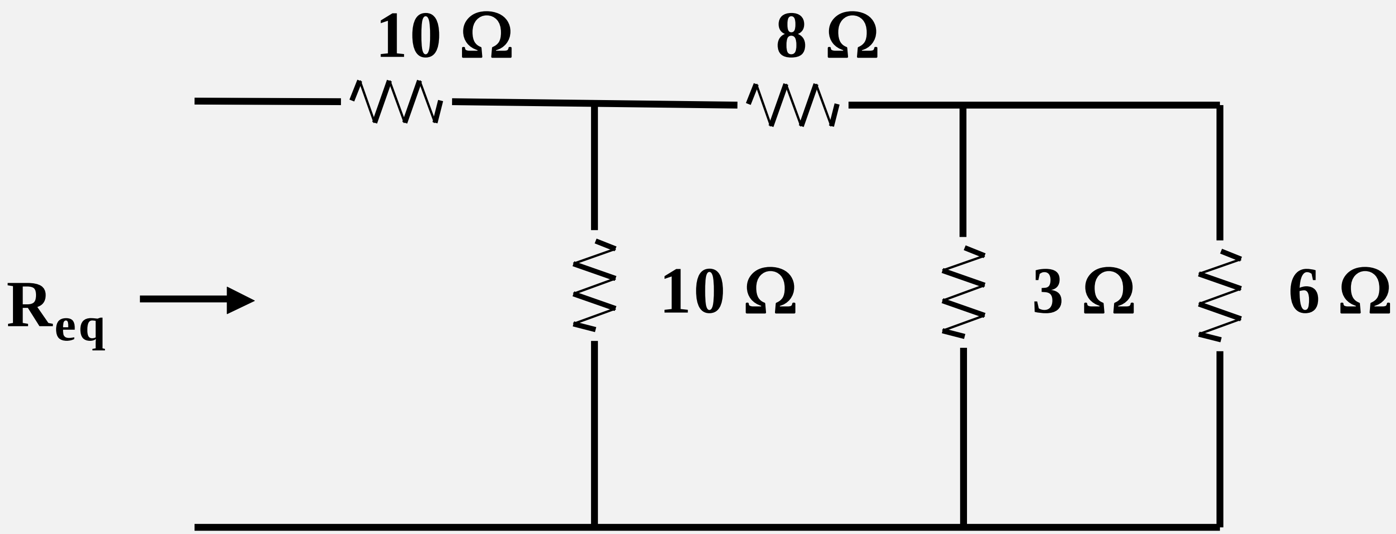


$$R_Z = \frac{R_2 R_Y}{R_2 + R_Y}$$

$$R_{eq} = R_Z + R_1$$

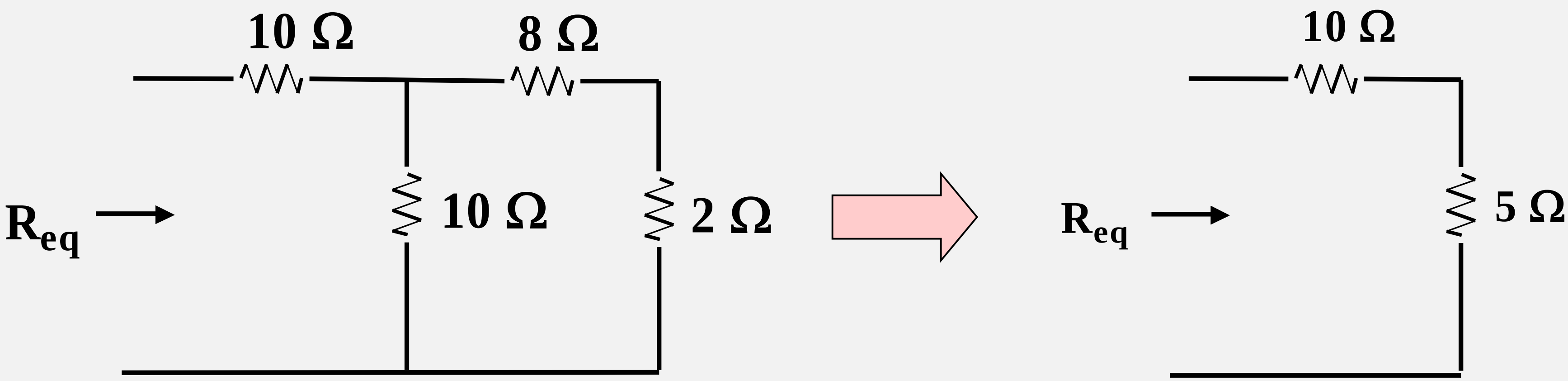
Figure : Resistance reduction, final steps.

Example : Given the circuit below. Find R_{eq}.



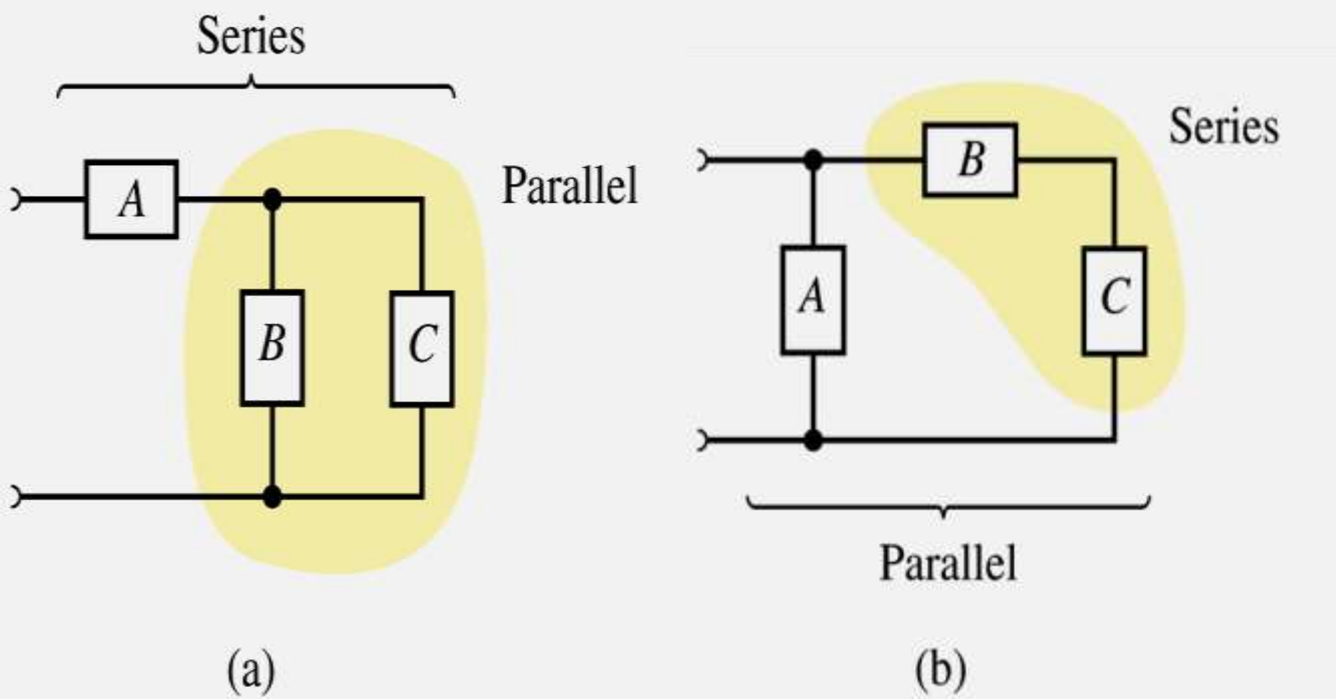
We start at the right hand side of the circuit and work to the left.

.



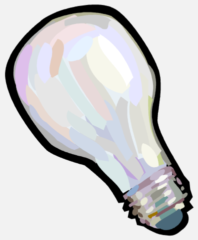
Ans: $R_{eq} = 15\Omega$

Series - Parallel Circuits



Current and Resistance in Series Circuits

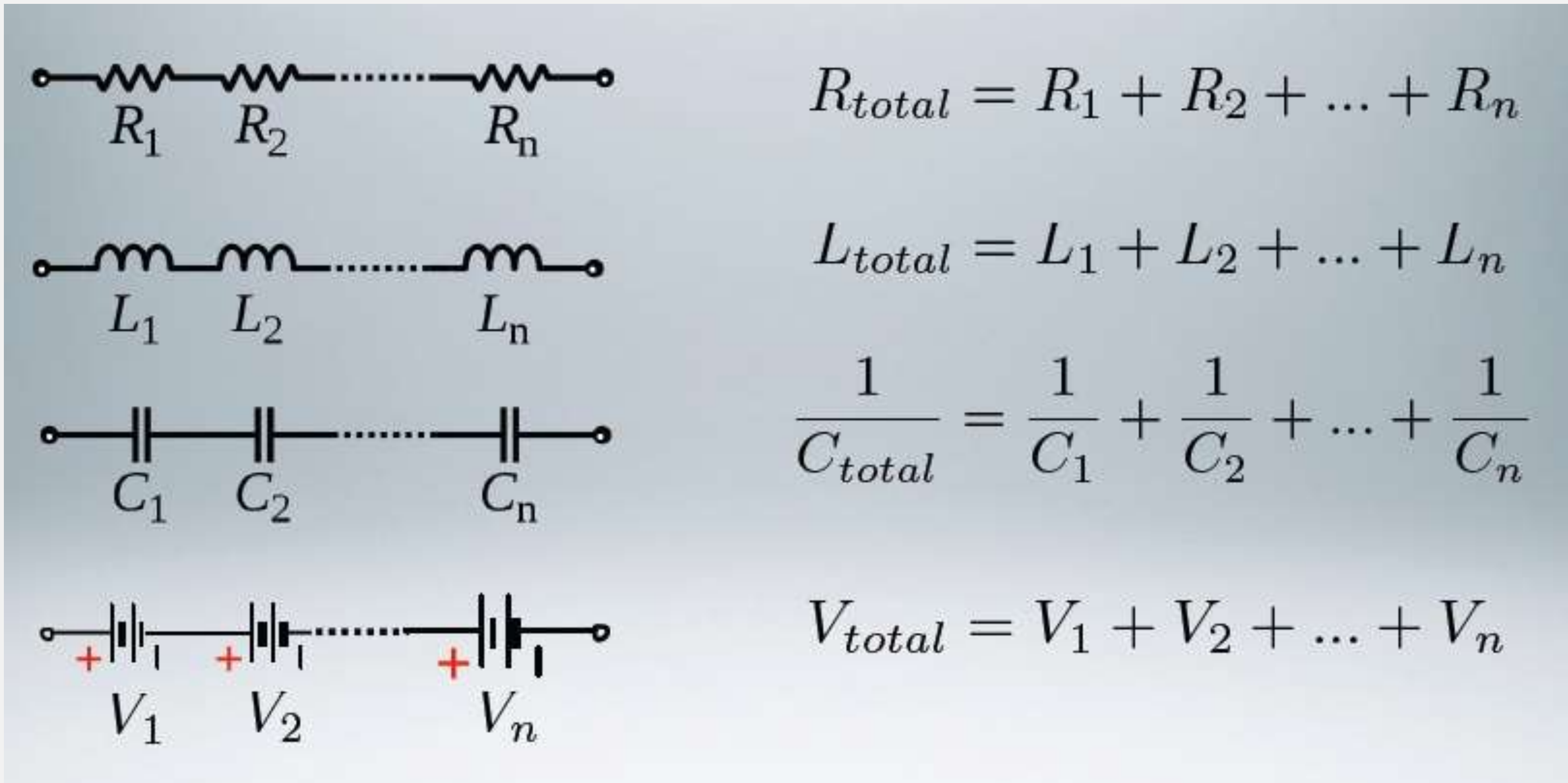
- For the series circuit the same current flows through both loads.
- The loads can be added together to calculate the total load.
- $R_{total} = R1 + R2$, where R_{total} is the total resistance, R1 is the resistance of one load, and R2 is the resistance of the other.
- The total load (resistance) in a series circuit with "n" loads is the sum of the resistance of the "n" objects. $R_{total} = R1 + R2 + \ldots + Rn$.



Total Voltage in a Series Circuit

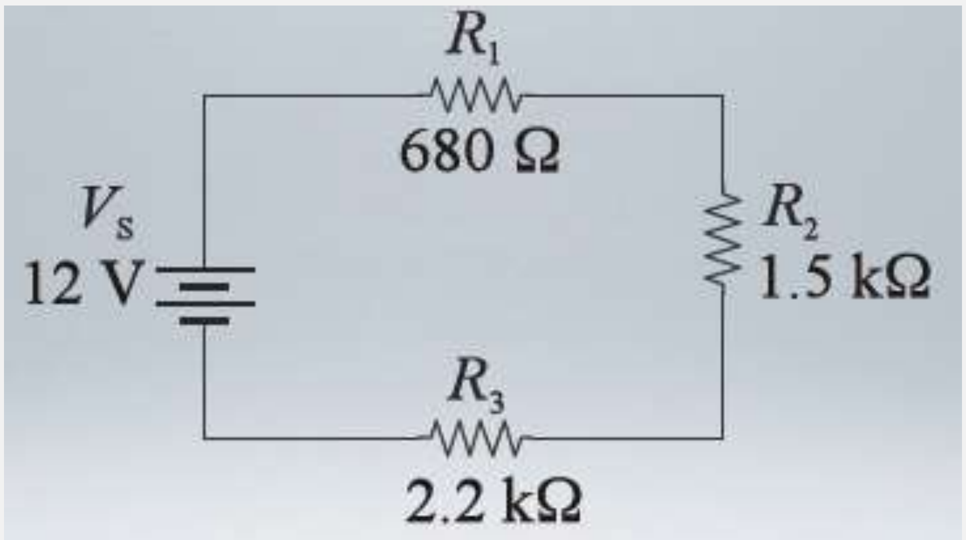
- Ohm's Law can be used to calculate the total voltage in a series circuit by calculating the sum of the voltage parts.
- V = V1 + V2, where V is the total voltage (battery voltage), V1 is the voltage at the first load, and V2 is the voltage at the other load.

Multiple elements in a series circuit



Example: Resistors in series

The resistors in a series circuit are 680 Ω, 1.5 kΩ, and 2.2 kΩ. What is the total resistance?



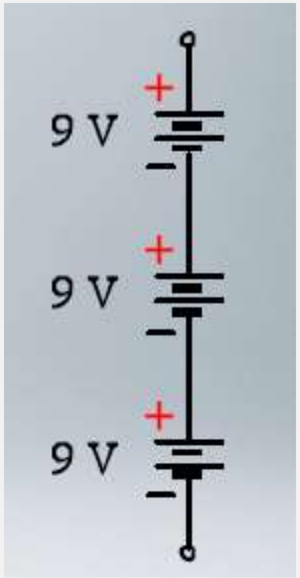
$$\begin{aligned} R_{total} &= R_1 + R_2 + R_3 \\ &= 680\Omega + 1500\Omega + 2200\Omega \\ &= 4380\Omega \\ &= 4.38k\Omega \end{aligned}$$

The current through each resistor?

$$I = \frac{V}{R_{total}} = \frac{12V}{4380\Omega} = 2.74mA$$

Example: Voltage sources in series

Find the total voltage of the sources shown

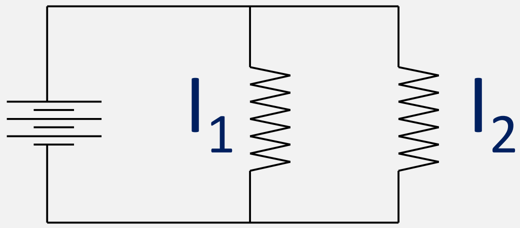


$$V_{total} = V_1 + V_2 + V_3 = 27V$$

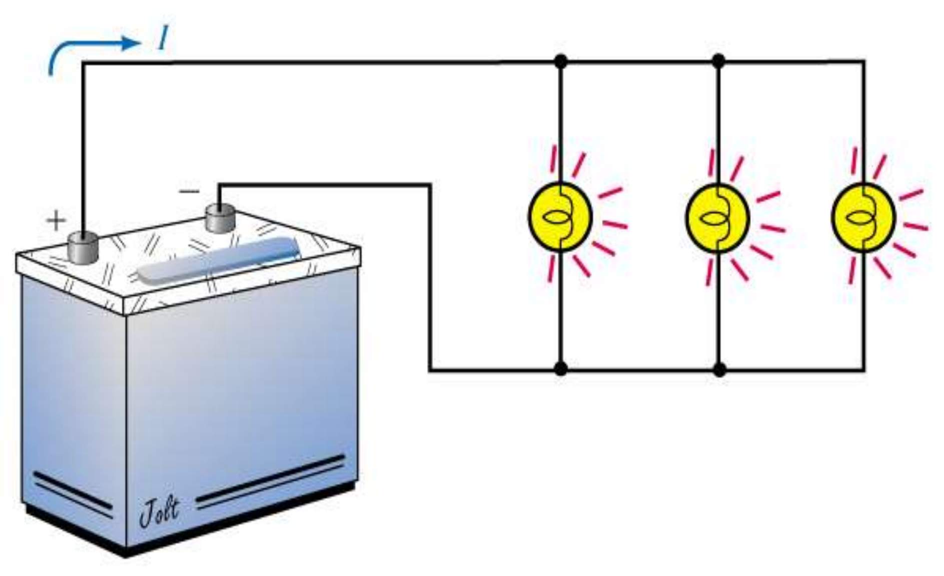
What happens if you reverse a battery?

Current in a Parallel Circuit

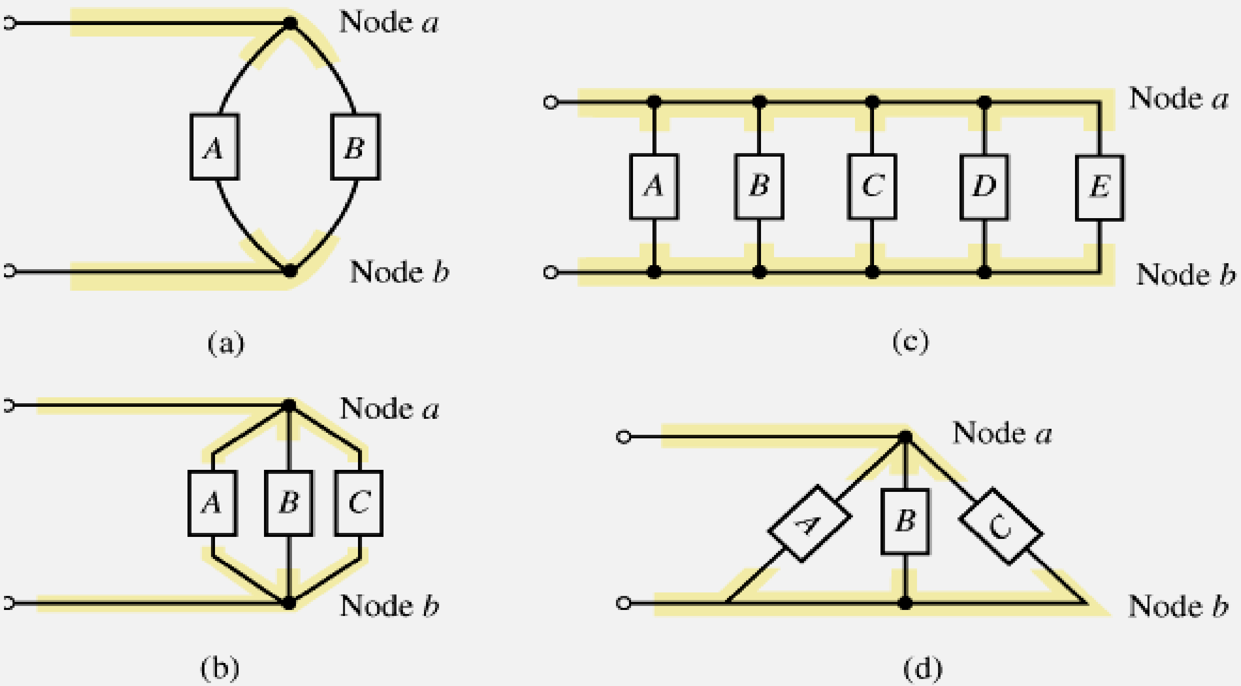
- The total current in a parallel circuit is the sum of the two parts.
- $I = I_1 + I_2$, where I is the total current, I_1 is the current through one load, and I_2 is the current through the other load.



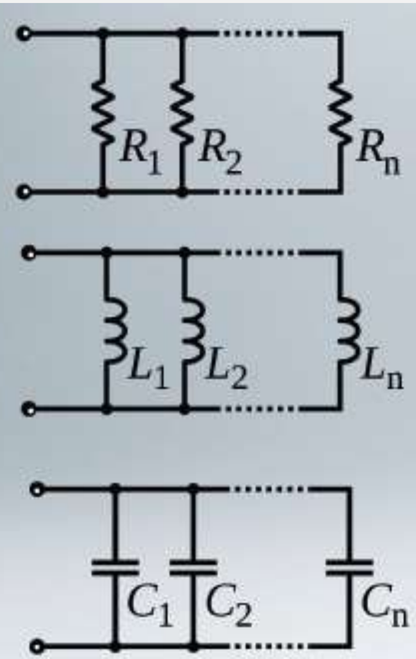
Parallel Circuits



Parallel Circuits



Multiple elements in a parallel circuit



$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}$$

$$\frac{1}{L_{total}} = \frac{1}{L_1} + \frac{1}{L_2} + \ldots + \frac{1}{L_n}$$

$$C_{total} = C_1 + C_2 + \ldots + C_n$$

For parallel voltage sources, the voltage is the same across all batteries, but the current supplied by each element is a fraction of the total current

Resistance in Parallel Circuits

Using Ohm's Law you can derive a formula for the equivalent resistance of two resistors in parallel.

$I_1 = V/R_1$

$I_2 = V/R_2$

$I \quad = I_1 + I_2 \qquad = V/R_1 + V/R_2$

$\quad\;\; = (VR_2 + VR_1)/R_1R_2$

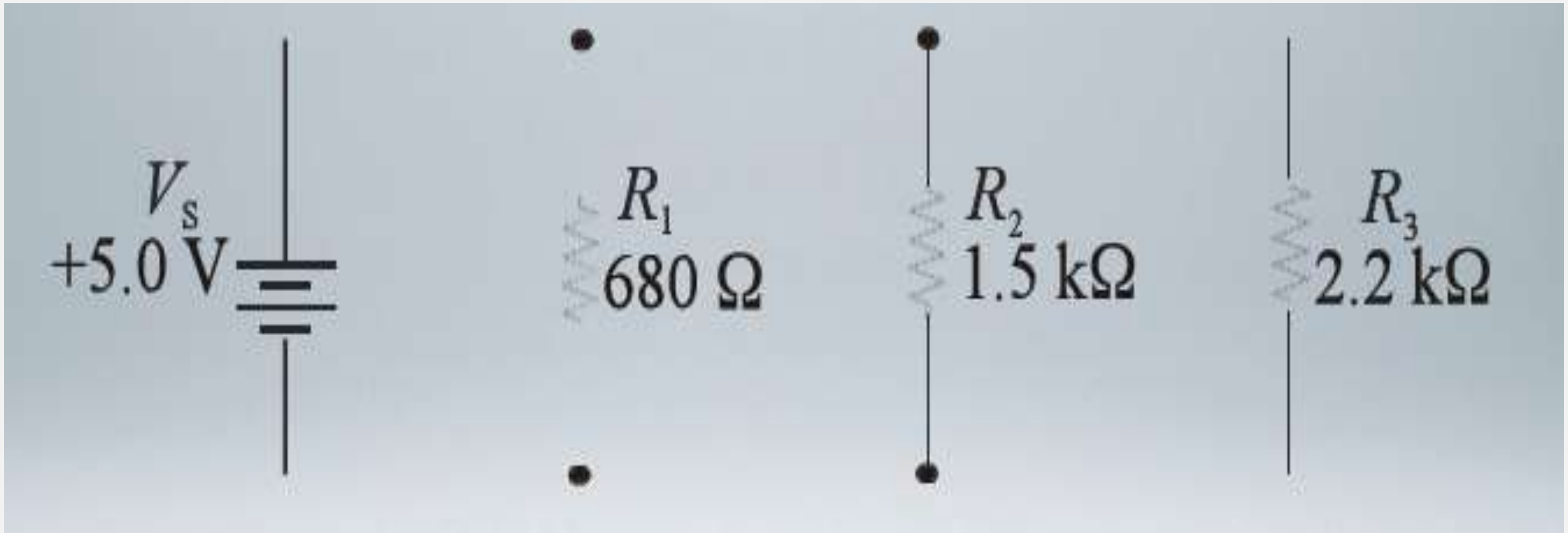
$\quad\;\; = V(R_2 + R_1)/ R_1R_2$

$R_{total} = V/(V(R_2 + R_1)/ \; R_1R_2 \qquad = \; R_1R_2/(R_1 + R_2)$

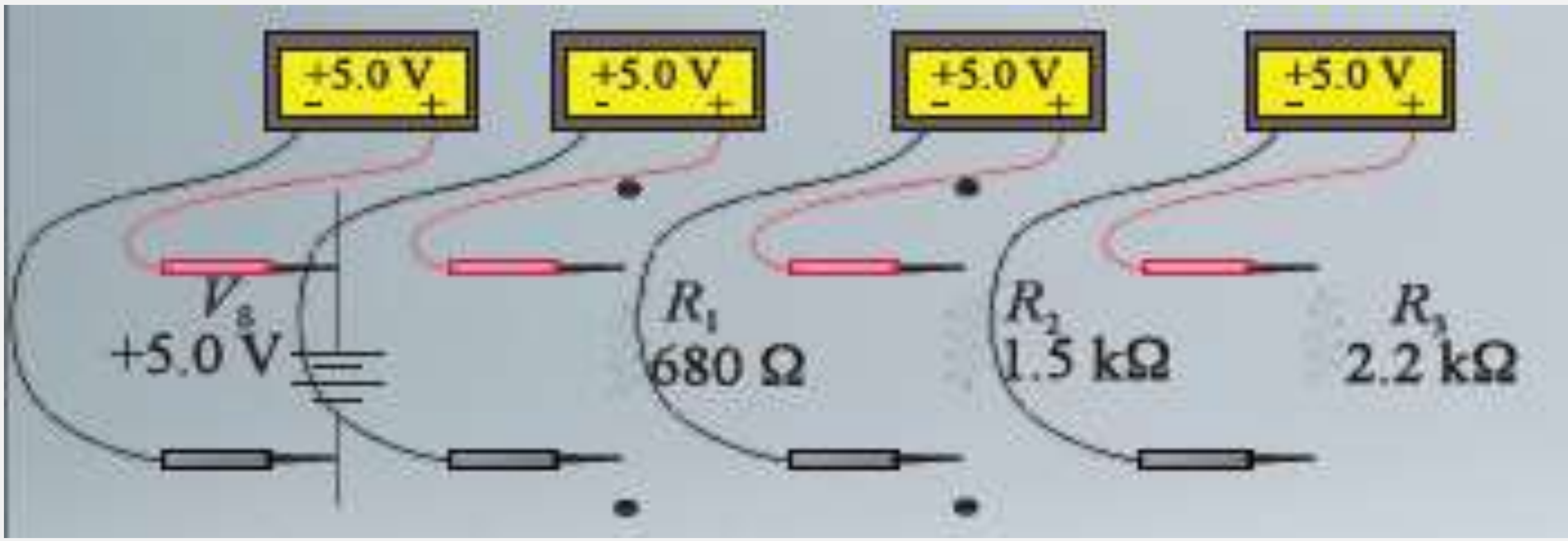
Example

The resistors in a parallel circuit are 680 Ω, 1.5 kΩ, and 2.2 kΩ.

1. What is the total resistance?
2. Voltage across each resistor?
3. Current through each resistor?



$$R_{total} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$
$$= 386\Omega$$



$I_1 = V/R_1 = 5/680 \quad = 5.73$ mA

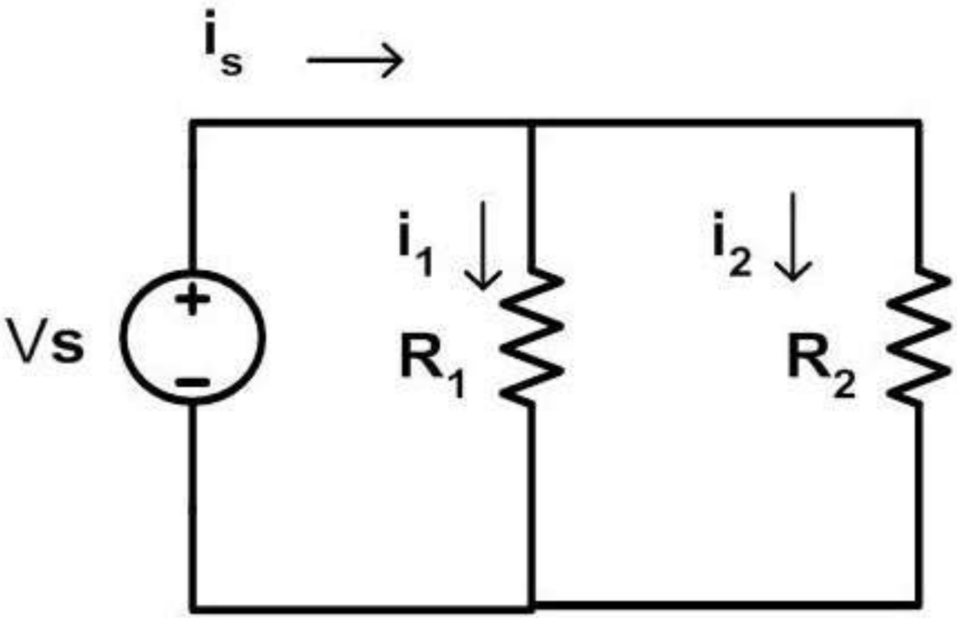
$I_2 = V/R_2 = 5/1500 \ = 3.33$ mA

$I_3 = V/R_3 = 5/2200 \ = 2.27$ mA

Voltage Division Rule & Current Division Rule

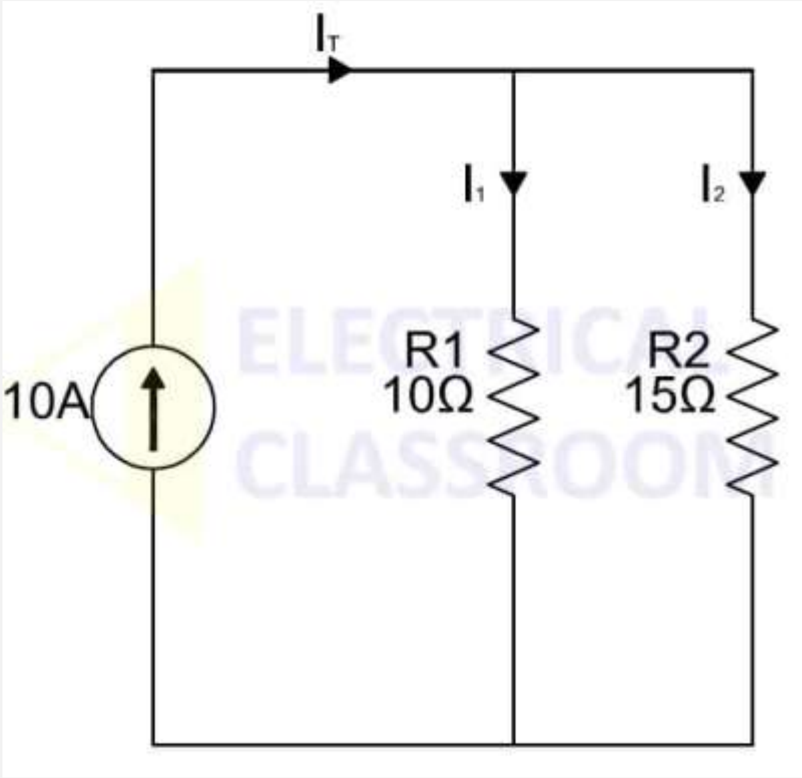
Current Divider Rule (CDR)

- Whenever current has to be divided among resistors in parallel, use current divider rule principle.



$$i_1 = \frac{R_2}{R_1 + R_2} i_s$$

$$i_2 = \frac{R_1}{R_1 + R_2} i_s$$



$$I_1 = I_T\, R_2 \,/\, (R_1 + R_2)$$

$$I_1 = 10*15 \,/\, (15 + 10)$$

$$= 150 \,/\, 25 = 6 \text{ Amperes}$$

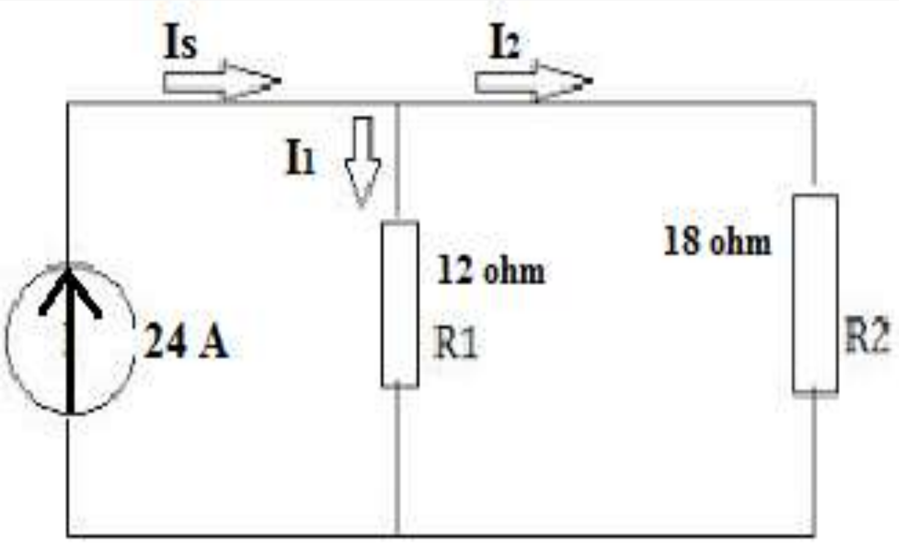
$$I_2 = I_T\, R_1 \,/\, (R_1 + R_2)$$

$$I_2 = 10*10 \,/\, (15 + 10)$$

$$= 100 \,/\, 25 = 4 \text{ Amperes}$$

$$I_T = I_1 + I_2$$

$$= 6 + 4 = 10 \text{ Amperes}$$



Use the current divider rule to find I_1 and I_2. Then find the power in R_1 and R_2 and P_T.

Applying the current divider rule:

$$I_1 = 24*18 / (12 + 18)$$
$$= 432 / 30$$
$$= 14.4\ A$$

$$I_2 = 24*12 / (12 + 18)$$
$$= 288 / 30$$
$$= 9.6\ A$$

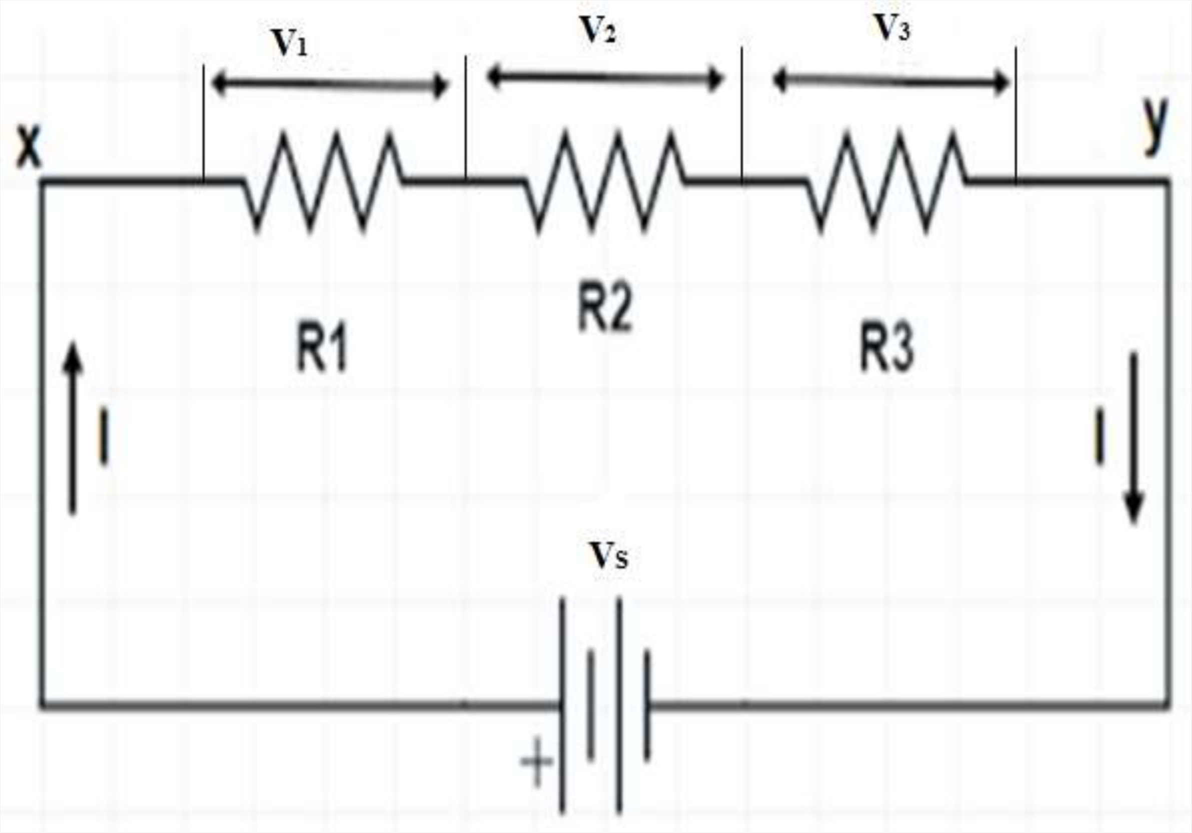
The power dissipated by each resistor is:

$$P_1 = I_1^2 * R_1 = 14.4^2 * 12$$
$$= 2488.32\ W$$

$$P_2 = I_2^2 * R_2 = 9.6^2 * 18$$
$$= 1658.88\ W$$

$$P_T = 4147.2\ W$$

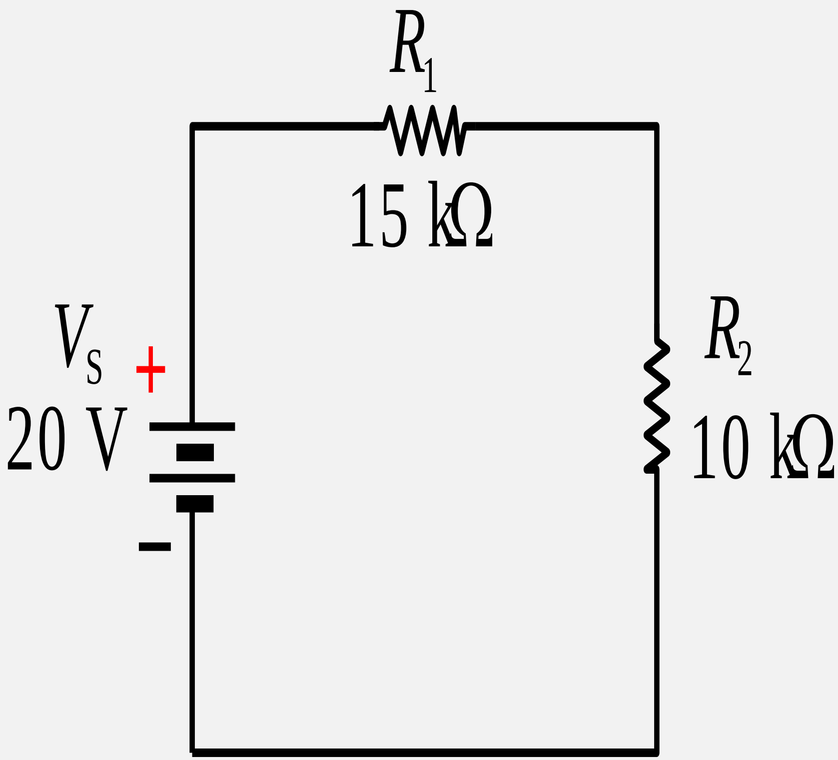
Voltage Division Rule



$$V_1 = \frac{R_1}{R_1+R_2+R_3} V_s$$

$$V_2 = \frac{R_2}{R_1+R_2+R_3} V_s$$

$$V_3 = \frac{R_3}{R_1+R_2+R_3} V_s$$



$$\mathbf{V_1 = V_s\, R_1 / (R_1 + R_2)}$$

$$V_1 = 20*15 / (15 + 10)$$

$$= 300 / 25 = 12 \text{ Volts}$$

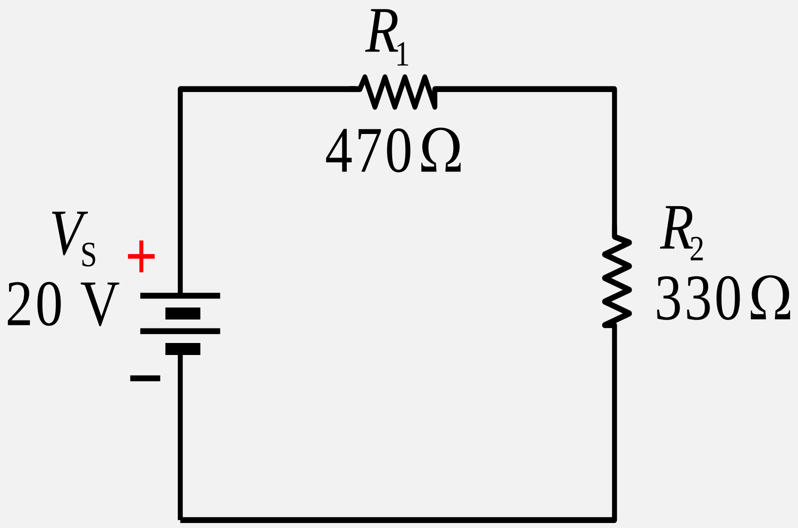
$$\mathbf{V_2 = V_s\, R_2 / (R_1 + R_2)}$$

$$V_2 = 20*10 / (15 + 10)$$

$$= 200 / 25 = 8 \text{ Volts}$$

$$\mathbf{V_s = V_1 + V_2}$$

$$= 12 + 8 = 20 \text{ Volts}$$



Use the voltage divider rule to find V_1 and V_2. Then find the power in R_1 and R_2 and P_T.

Applying the voltage divider rule:

$$V_1 = 20\text{ V}\left(\frac{470\ \Omega}{800\ \Omega}\right) = 11.75\text{ V}$$

$$V_2 = 20\text{ V}\left(\frac{330\ \Omega}{800\ \Omega}\right) = 8.25\text{ V}$$

The power dissipated by each resistor is:

$$P_1 = \frac{(11.75\text{ V})^2}{470\ \Omega} = 0.29\text{ W}$$

$$P_2 = \frac{(8.25\text{ V})^2}{330\ \Omega} = 0.21\text{ W}$$

P_T = 0.5 W

Quiz

1. In a series circuit with more than one resistor, the current is

    a. larger in larger resistors

    b. smaller in larger resistors

    c. always the same in all resistors

    d. there is not enough information to say

Quiz

2. In a series circuit with more than one resistor, the voltage is

a. larger across larger resistors

b. smaller across larger resistors

c. always the same across all resistors

d. there is not enough information to say

Quiz

3. If three equal resistors are in series, the total resistance is

   a. one third the value of one resistor

   b. the same as one resistor

   c. three times the value of one resistor

   d. there is not enough information to say

Quiz

4. A series circuit cannot have

a. more than two resistors

b. more than one voltage source

c. more than one path

d. all of the above

Quiz

5. In a closed loop, the algebraic sum of all voltages (both sources and drops)

   a. is 0

   b. is equal to the smallest voltage in the loop

   c. is equal to the largest voltage in the loop

   d. depends on the source voltage

Quiz

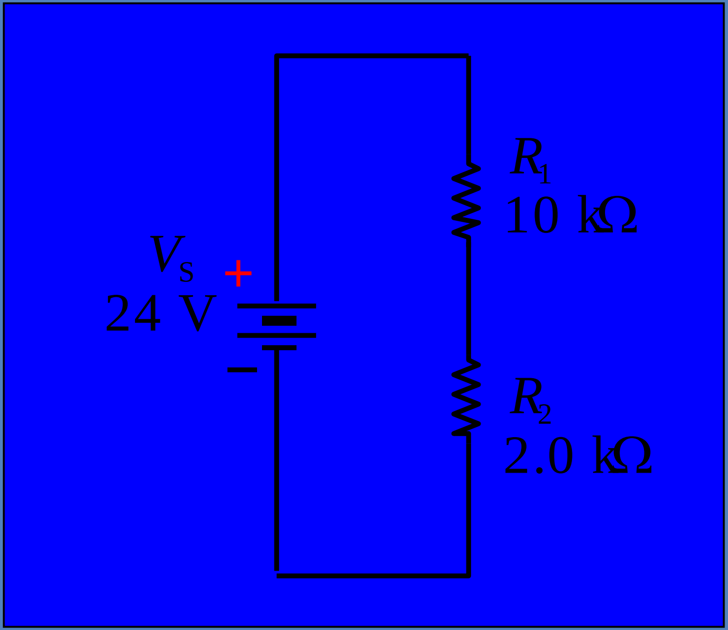
6. The current in the 10 kΩ resistor is

a. 0.5 mA

b. 2 mA

c. 2.4 mA

d. 10 mA



Quiz

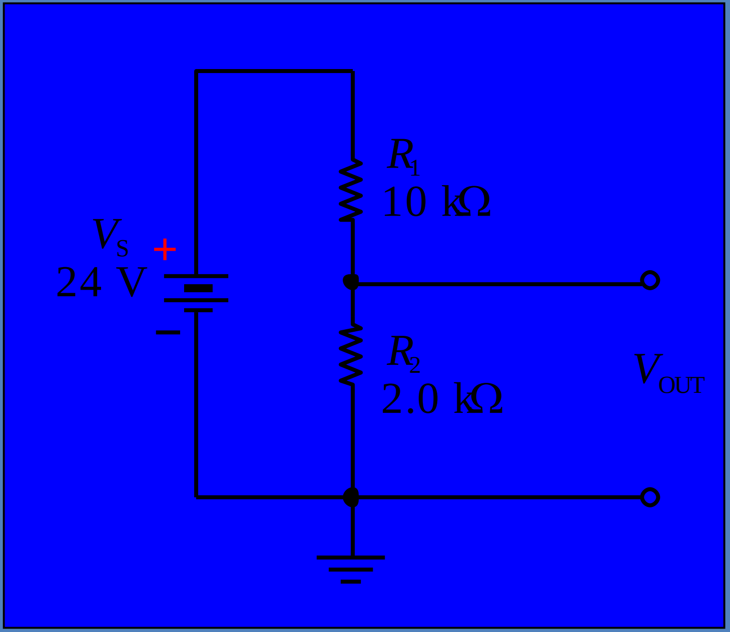
7. The output voltage from the voltage divider is

a. 2 V

b. 4 V

c. 12 V

d. 20 V



Quiz

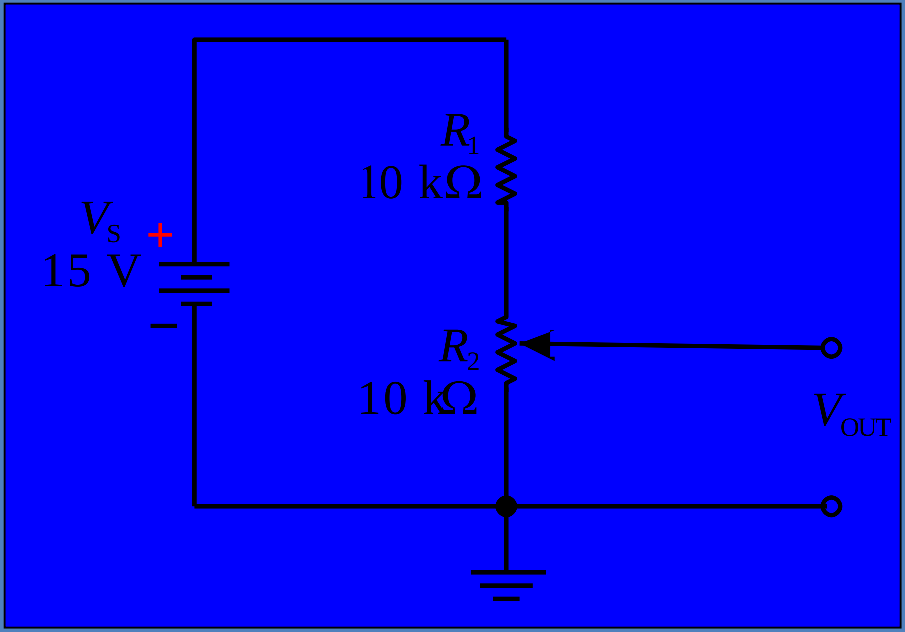
8. The smallest output voltage available from the voltage divider is

a. 0 V

b. 1.5 V

c. 5.0 V

d. 7.5 V



Quiz

9. The total power dissipated in a series circuit is equal to the

a. power in the largest resistor

b. power in the smallest resistor

c. average of the power in all resistors

d. sum of the power in all resistors

Quiz

10. The meaning of the voltage V_{AB} is the voltage at

a. Point A with respect to ground

b. Point B with respect to ground

c. The average voltage between points A and B.

d. The voltage difference between points A and B.

Quiz

Answers:

1. c
2. a
3. c
4. c
5. a
6. b
7. b
8. a
9. d
10. d