

UNIT 1: DC CIRCUITS

Lecture 3

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Kirchhoff's Law

- Ohm's law by itself **is not sufficient** to analyze circuits.
- However, when it is coupled with Kirchhoff's two laws, we have a sufficient, powerful set of tools for analyzing a large variety of electric circuits.
- These laws are:
 1. Kirchhoff's Voltage Law (KVL)
 2. Kirchhoff's Current Law (KCL)

Kirchhoff's Current Law (KCL)

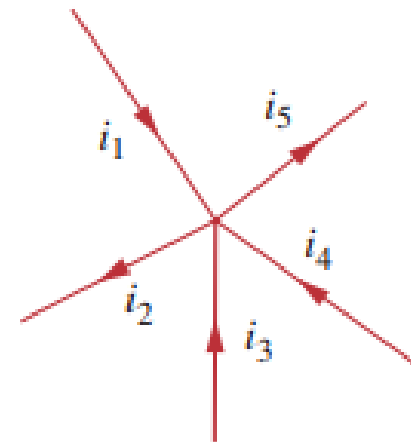
- It states that:

“the algebraic sum of currents entering a node is zero”.

OR

“ Sum of currents entering a node = Sum of currents leaving a node “

- Based on Law of Conservation of Charge.
- Mathematically, $\sum I = 0$



QUICK QUIZ (Poll 1)

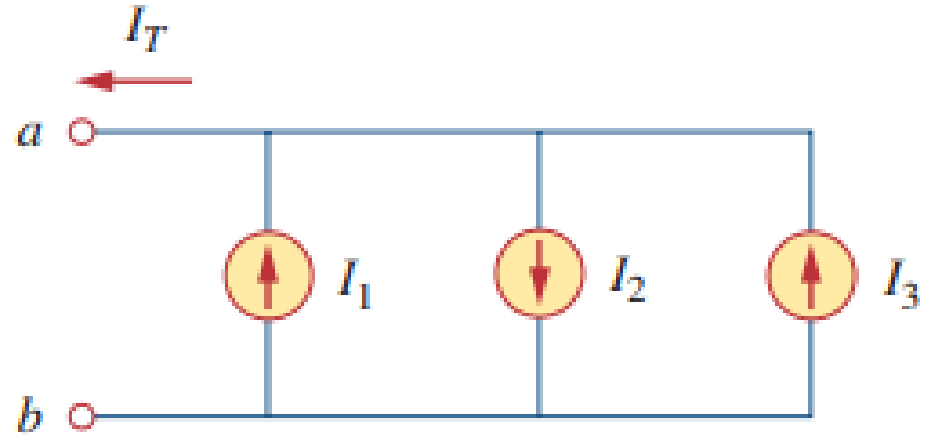
KCL equation for the given network is:

A. $I_1 + I_2 + I_3$

B. $I_1 + I_2 - I_3$

C. $I_1 - I_2 + I_3$

D. $-I_1 - I_2 + I_3$



Kirchhoff's Voltage Law (KVL)

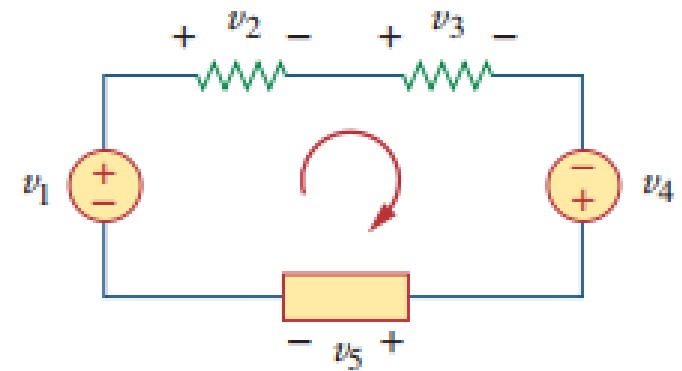
- It states that:

“algebraic sum of all voltages around a closed path (or loop) is zero.”

OR

“Sum of voltage drops = Sum of voltage rises.”

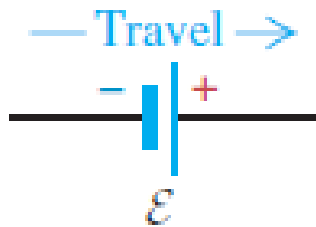
- Based on Law of Conservation of Energy
- Mathematically, $\sum V = 0$



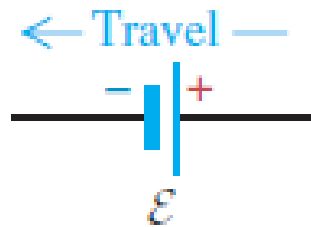
Sign Convention for KVL

(a) Sign conventions for emfs

$+\mathcal{E}$: Travel direction from $-$ to $+$:

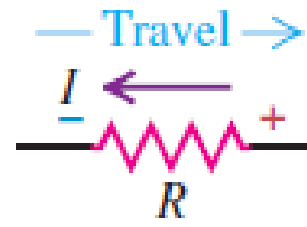


$-\mathcal{E}$: Travel direction from $+$ to $-$:

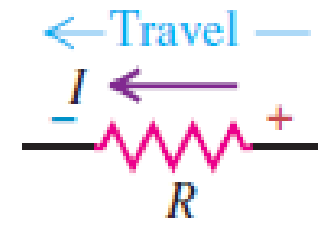


(b) Sign conventions for resistors

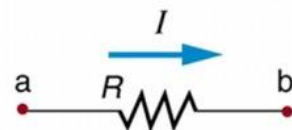
$+IR$: Travel *opposite* to current direction:



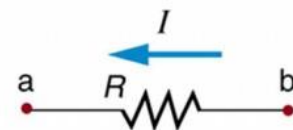
$-IR$: Travel *in* current direction:



Direction of traverse a \longrightarrow b Direction of traverse a \longrightarrow b

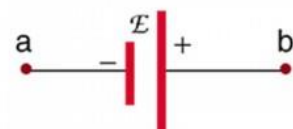


$$\Delta V = V_b - V_a = -IR$$

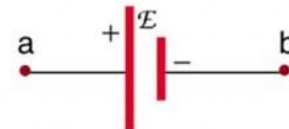


$$\Delta V = V_b - V_a = +IR$$

Direction of traverse a \longrightarrow b Direction of traverse a \longrightarrow b



$$\Delta V = V_b - V_a = +\mathcal{E}$$



$$\Delta V = V_b - V_a = -\mathcal{E}$$

Let us Recall!

- Taking Clockwise direction (Def. 1):

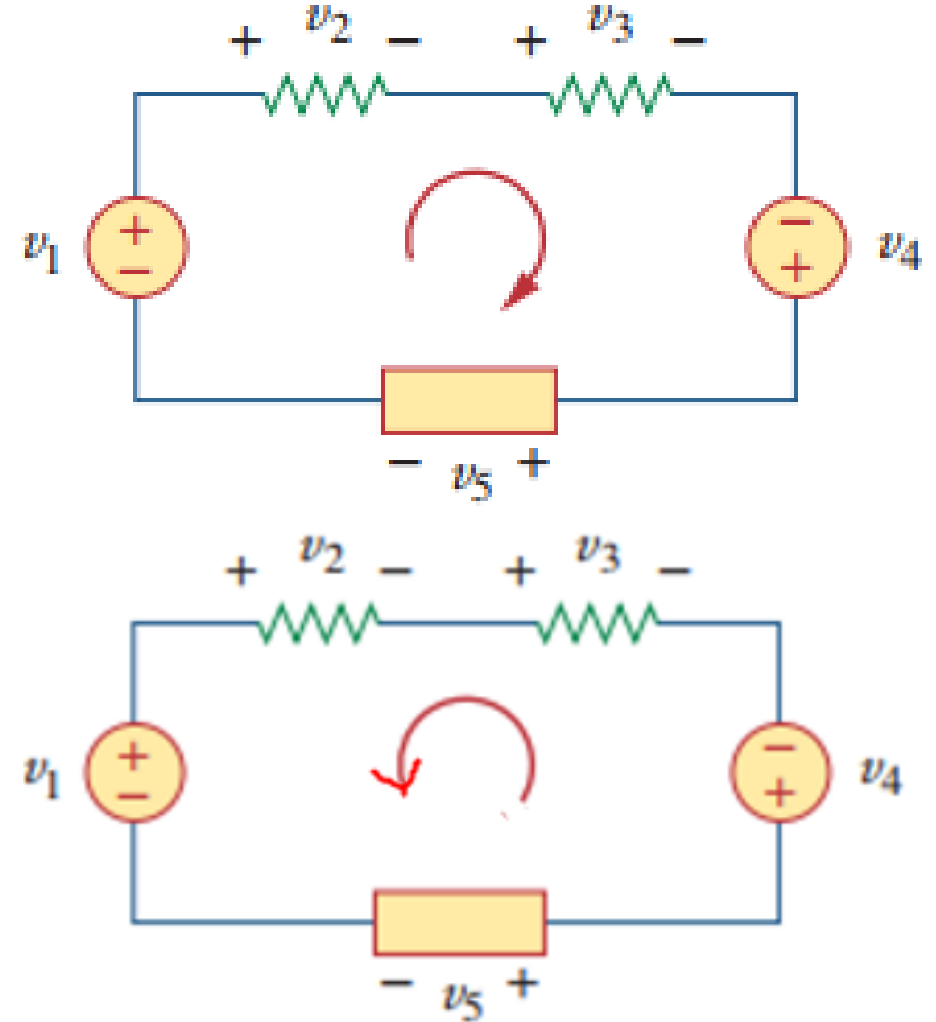
$$+V_1 - V_2 - V_3 + V_4 - V_5 = 0$$

- Taking Anti-clockwise direction(Def. 1):

$$-V_4 + V_3 + V_2 - V_1 + V_5 = 0$$

- Voltage rise = Voltage drop

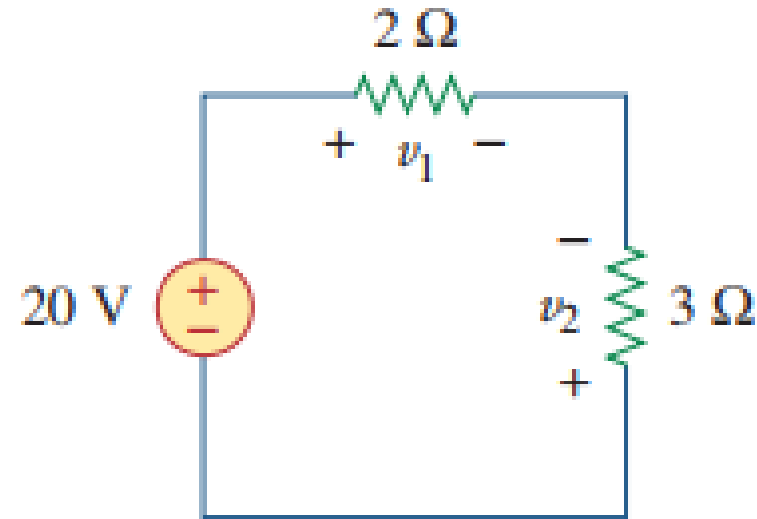
$$+V_1 + V_4 = V_2 + V_3 + V_5$$



QUICK QUIZ (Poll 2)

Find voltages V_1 and V_2 in the given circuit:

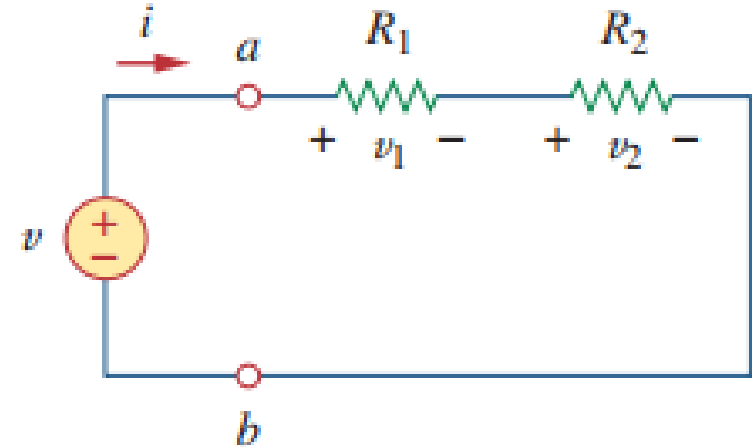
- A.* $V_1 = 16\text{ V}$ and $V_2 = 12\text{ V}$
- B.* $V_1 = 16\text{ V}$ and $V_2 = -8\text{ V}$
- C.* $V_1 = 8\text{ V}$ and $V_2 = -12\text{ V}$
- D.* $V_1 = -12\text{ V}$ and $V_2 = 8\text{ V}$



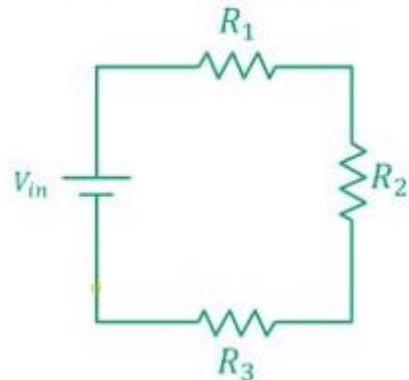
Voltage Division Rule

- The important relations are:

$$v_1 = \frac{R_1}{R_1 + R_2} v, \quad v_2 = \frac{R_2}{R_1 + R_2} v$$



VOLTAGE DIVISION RULE FOR 3- RESISTORS



$$V_1 = \frac{R_1}{R_1 + R_2 + R_3} * V_{in}$$

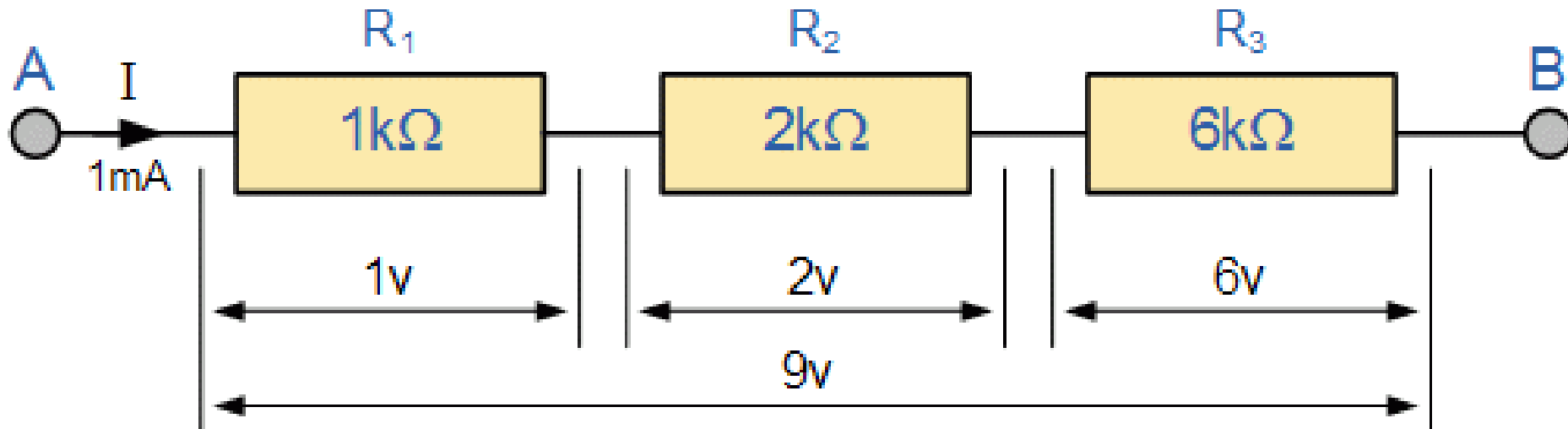
$$V_2 = \frac{R_2}{R_1 + R_2 + R_3} * V_{in}$$

$$V_3 = \frac{R_3}{R_1 + R_2 + R_3} * V_{in}$$

Voltage Division Rule for N-Resistors

$$v_n = \frac{R_n}{R_1 + R_2 + \dots + R_N} v$$

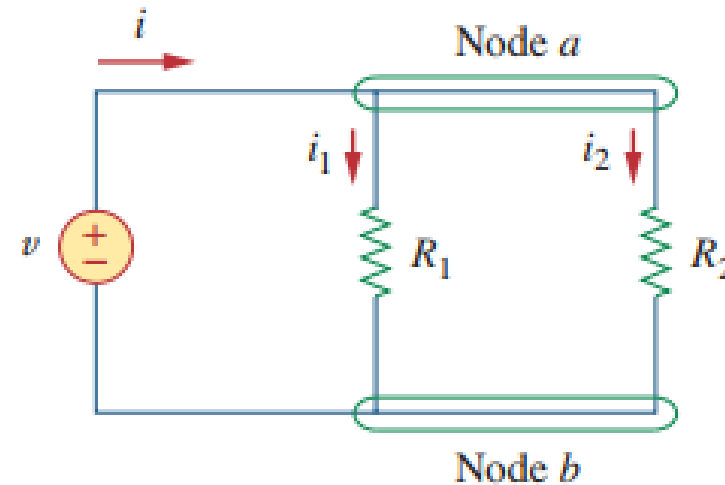
Example for Voltage Division Rule



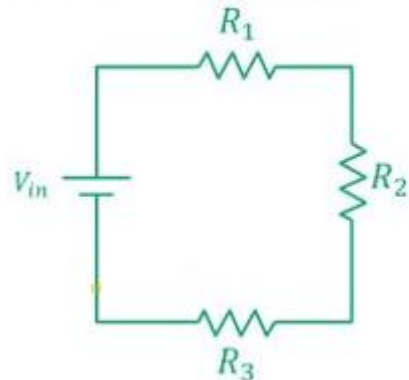
Current Division Rule

- The important relations are:

$$i_1 = \frac{R_2 i}{R_1 + R_2}, \quad i_2 = \frac{R_1 i}{R_1 + R_2}$$



VOLTAGE DIVISION RULE FOR 3- RESISTORS



$$V_1 = \frac{R_1}{R_1 + R_2 + R_3} * V_{in}$$

$$V_2 = \frac{R_2}{R_1 + R_2 + R_3} * V_{in}$$

$$V_3 = \frac{R_3}{R_1 + R_2 + R_3} * V_{in}$$

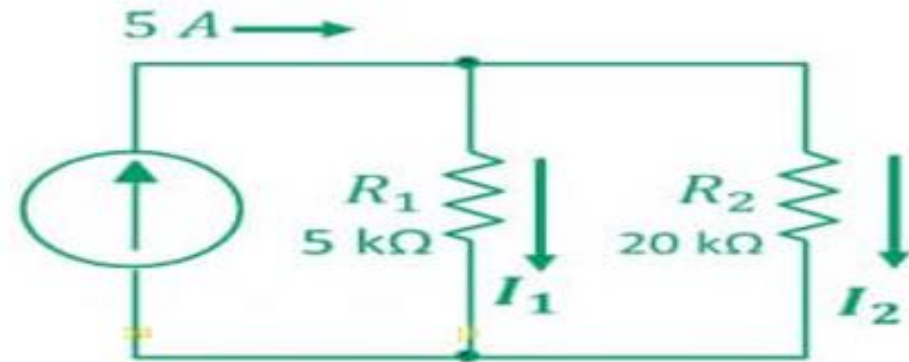
Voltage Division Rule for N-Resistors

$$v_n = \frac{R_n}{R_1 + R_2 + \dots + R_N} v$$

QUICK QUIZ (Poll 3)

Find current across two resistors?

- A. $I_1 = 4\text{ A}$ and $I_2 = 16\text{ A}$*
- B. $I_1 = -2\text{ A}$ and $I_2 = 1\text{ A}$*
- C. $I_1 = 4\text{ A}$ and $I_2 = 1\text{ A}$*
- D. $I_1 = 1\text{ A}$ and $I_2 = 4\text{ A}$*



Applications of Kirchhoff's Laws

- They can be used to analyze **any electrical circuit**.
- Computation of current and voltage of **complex** circuits.

Limitations of Kirchhoff's Laws

- The limitation of Kirchhoff's both laws is that it works under the assumption that there is **no fluctuating magnetic field** in the closed loop and the current flows **only through conductors and wires**.

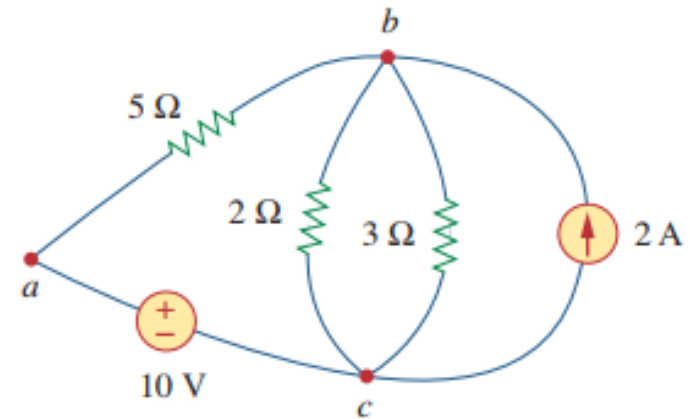
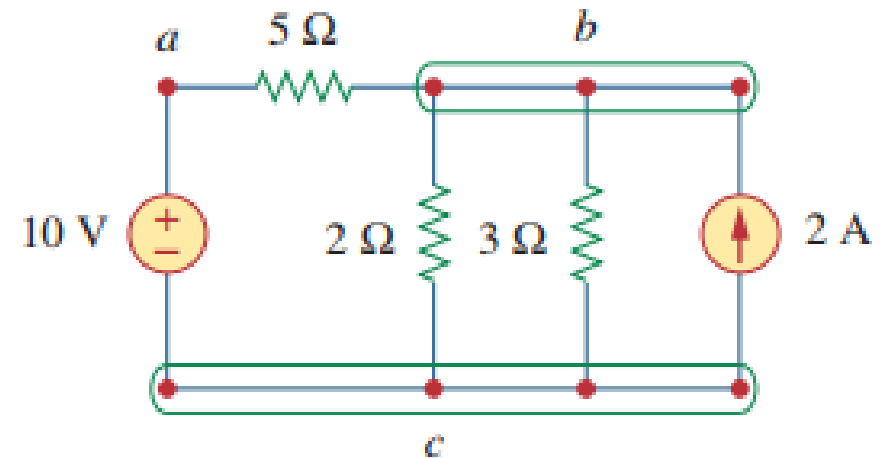
$$\frac{\partial \phi_B}{\partial t} = 0 \quad \text{Outside elements}$$
$$\frac{\partial q}{\partial t} = 0 \quad \begin{array}{c} \text{Inside elements} \\ \swarrow \quad \downarrow \quad \searrow \\ \text{wires} \quad \text{resistors} \quad \text{sources} \end{array}$$

Nodes, Branches, and Loops

- A **branch** represents a single element such as a voltage source or a resistor.
- A **node** is the point of connection between two or more branches.
- A **loop** is any closed path in a circuit

NOTE:

- Two or more elements are in **series** if they exclusively **share a single node** and consequently carry the same current.
- Two or more elements are in **parallel** if they are connected to the **same two nodes** and consequently have the same voltage across them.



QUICK QUIZ (Poll 4)

How many branches, nodes and independent loops are present in the given circuit?

- A. $b=3, n=5, l=6$
- B. $b=5, n=3, l=6$
- C. $b=5, n=3, l=3$
- D. $b=3, n=5, l=3$

