UCONN
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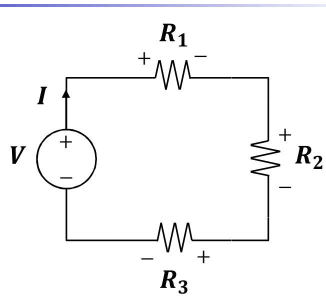
Introduction to Bioelectricity Part II

ENGR 1166 Biomedical Engineering

Recap

- **Electric current** is the flow of electrically charged particles through a medium. It is measured in Ampere (A)
- **Voltage** is the work required to move a unit charge between two points (+) and (-). It is measured in Volt (V)
- A **resistor** is a circuit element opposing the current by producing a voltage drop between the terminals

Recap



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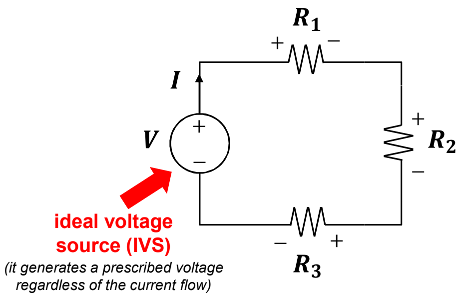

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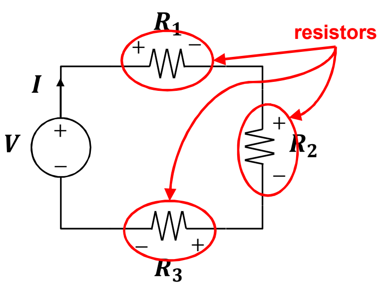
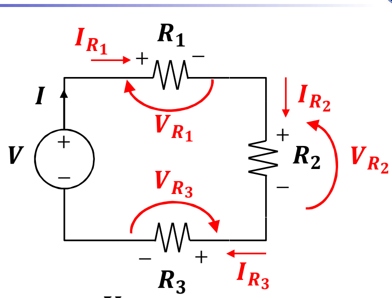


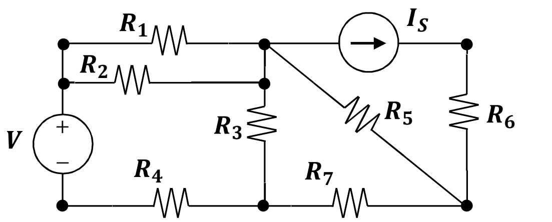
Recap (Ohm's Law)



$$R_j = \frac{V_{R_j}}{I_{R_j}} \quad j = 1, 2, 3$$

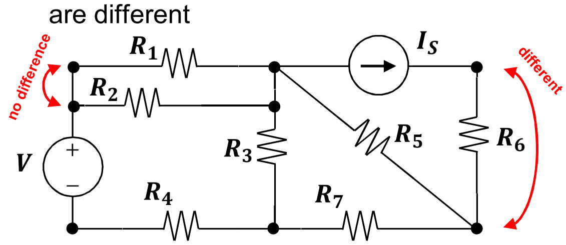
Nodes in a circuit

- A **node** is any point on a circuit where two or more circuit elements meet



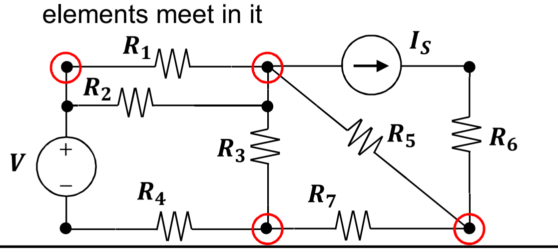
Nodes in a circuit

- A **node** is any point on a circuit where two or more circuit elements meet
- Two nodes are different if their voltages are different



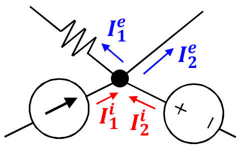
Nodes in a circuit

- A **node** is any point on a circuit where two or more circuit elements meet
- A node is **essential** if 3 or more circuit elements meet in it



Kirchhoff's current law (KCL)

At any node in an electrical circuit, the sum of the currents flowing into that node is equal to the sum of currents flowing out of that node



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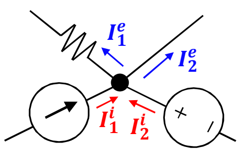
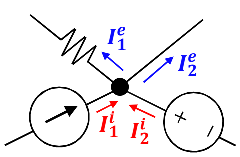


$$I_1^i + I_2^i = I_1^e + I_2^e$$

Kirchhoff's current law (KCL)

Equivalently, at any node in an electrical circuit, the **algebraic sum** of the currents is equal to zero

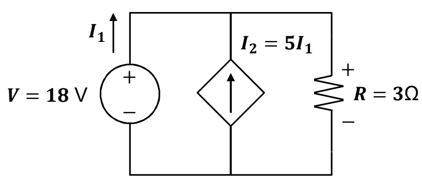


$$\sum_k I_k^e - \sum_h I_h^i = 0$$

What KCL tells us…

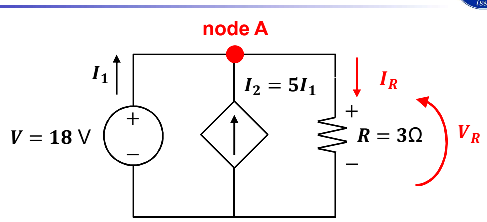
- **Current cannot be lost** as it flows around the circuit: net charge cannot accumulate within the circuit
- Any current that enters one terminal of a circuit element must exit at the other terminal of the element
- Current can only flow in a **closed circuit**

KCL: example 1



What is the power of each circuit element?

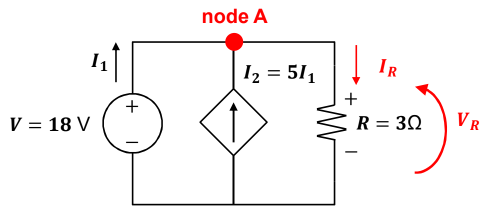
KCL: example 1



KCL at node A: $-I_1 - I_2 + I_R = 0$

Ohm's law: $V_R = R \times I_R$

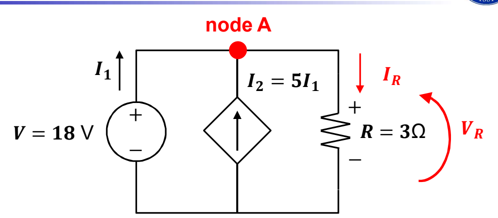
KCL: example 1



KCL at node A: $\boldsymbol{I_R = 6\,I_1}$

Ohm's law: $\boldsymbol{I_R = V_R/R = V/R = 18/3 = 6}$ A

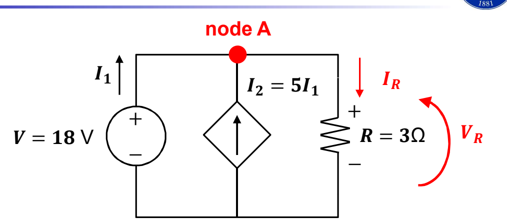
KCL: example 1



KCL at node A: $\boldsymbol{I_R = 6\,I_1 \Rightarrow I_1 = I_R/6 = 1}$ A

Ohm's law: $\boldsymbol{I_R = V_R/R = V/R = 18/3 = 6}$ A

KCL: example 1

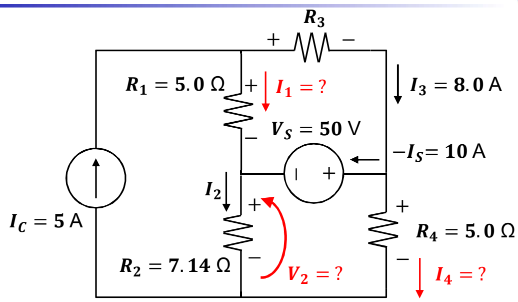


Power of IVS: $\boldsymbol{P_{IVS} = -V \times I_1 = -18}$ W

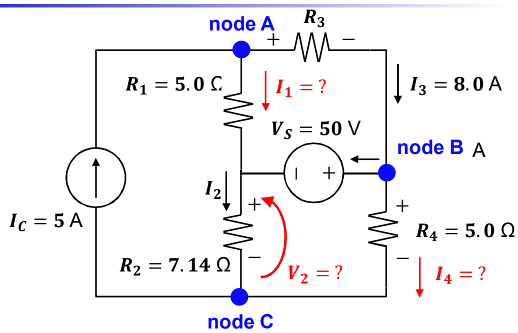
Power of ICS: $\boldsymbol{P_{ICS} = -V \times I_2 = -90}$ W

Power of resistor: $\boldsymbol{P_R = V \times I_R = +108}$ W

KCL: example 2



KCL: example 2



KCL: example 2

KCL at node A: $-I_C + I_1 + I_3 = 0$

KCL at node B: $-I_3 - I_S + I_4 = 0$

KCL at node C: $-I_2 - I_4 + I_C = 0$

Ohm's law: $V_2 = R_2 I_2$

KCL: example 2

KCL at node A: $-5.0 + I_1 + 8.0 = 0$

KCL at node B: $-8.0 + 10 + I_4 = 0$

KCL at node C: $-I_2 - I_4 + 5.0 = 0$

Ohm's law: $V_2 = 7.14\, I_2$

$$I_1 = -3.0 \text{ A}$$
$$I_2 = +7.0 \text{ A}$$
$$I_4 = -2.0 \text{ A}$$
$$V_2 = +49.98 \text{ V}$$

KCL: example 2

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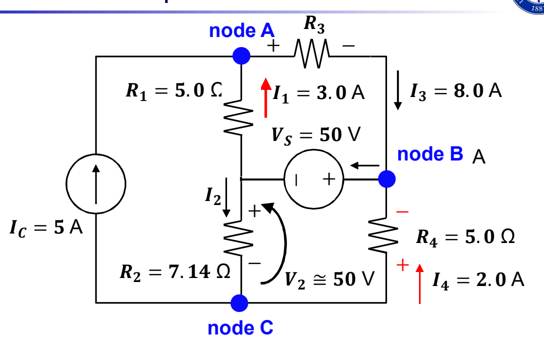
$$V_2 = +49.98 \text{ V}$$

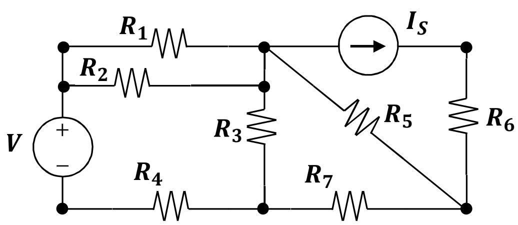
The direction of these two currents must be fixed!

KCL: example 2



Paths in a circuit

- A **path** is a connected group of circuit elements with no repetitions



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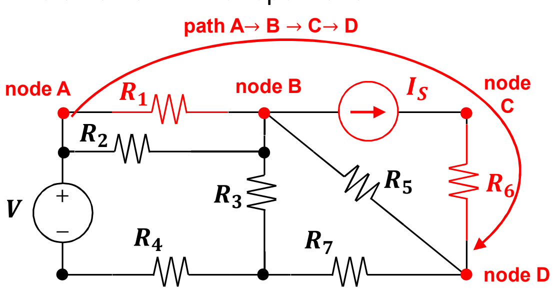
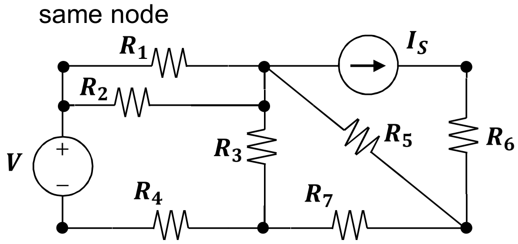


Paths in a circuit

- A **path** is a connected group of circuit elements with no repetitions
- A path is **closed** if it starts and ends at the same node



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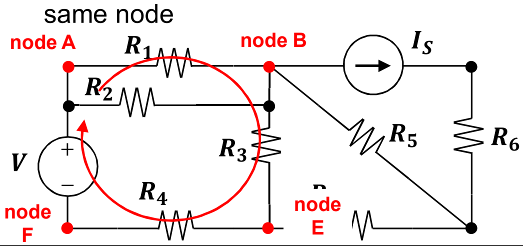
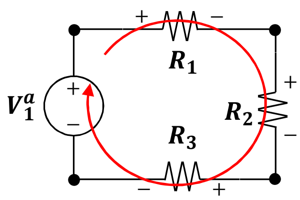


Kirchhoff's voltage law (KVL)

In a **closed path** the sum of voltages across active elements must be equal to the sum of voltage drops across passive elements



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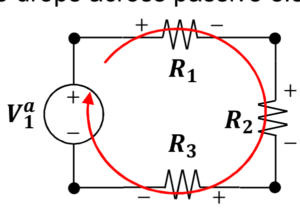
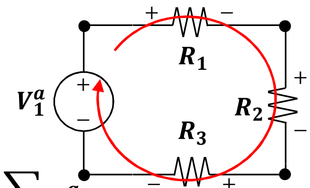


$$V_1^a = V_{R_1} + V_{R_2} + V_{R_3}$$

Kirchhoff's voltage law (KVL)

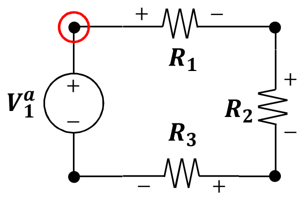
Equivalently, the **directed sum** of voltages along any closed path in a circuit is zero



$$\sum_k V_{R_k} - \sum_h V_h^a = 0$$

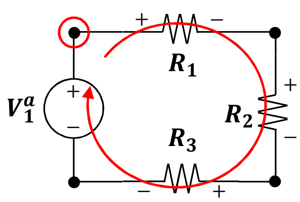
KVL in practice…

- ❑ Choose a **start node** in the closed path



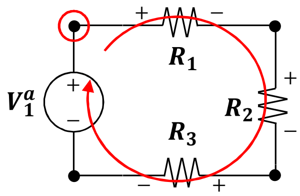
KVL in practice…

- ❑ Explore the closed path clockwise until the start node is reached again



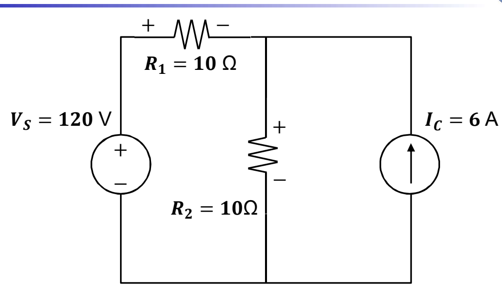
KVL in practice…

- For every circuit element encountered, put down the voltage. The sign of the voltage is the sign at the first terminal encountered



$$V_{R_1} + V_{R_2} + V_{R_3} - V_1^a = 0$$

KVL: example



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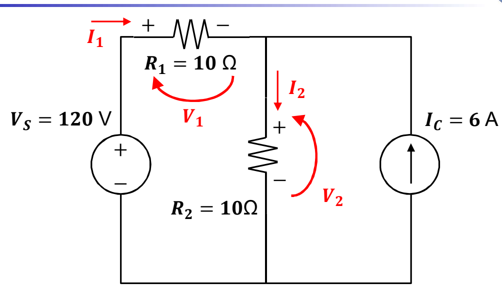
KVL: example



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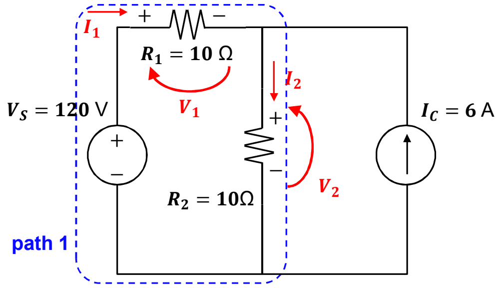
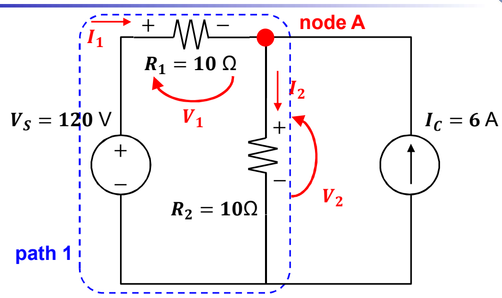


KVL at path 1: $V_1 + V_2 - V_S = 0$

Ohm's law: $V_1 = R_1 I_1$; $V_2 = R_2 I_2$

KVL: example



KVL at path 1: $V_1 + V_2 - V_S = 0$

KCL at node A: $-I_1 - I_C + I_2 = 0$

KVL: example

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Ohm's law: $V_1 = R_1 I_1$; $V_2 = R_2 I_2$

KVL: example

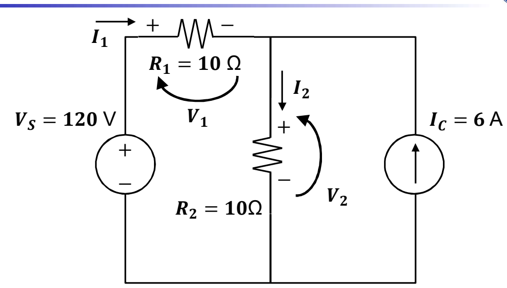
KVL at path 1: $V_1 + V_2 - 120 = 0$

KCL at node A: $-I_1 - 6 + I_2 = 0$

Ohm's law: $V_1 = 10\,I_1$; $V_2 = 10\,I_2$

$$I_1 = +3.0 \text{ A}$$
$$I_2 = +9.0 \text{ A}$$
$$V_1 = +30 \text{ V}$$
$$V_2 = +90 \text{ V}$$

KVL: example



$P_{IVS} = -V_S I_1 = -360$ W $P_1 = V_1 I_1 = +90$ W

$P_{ICS} = -V_2 I_C = -540$ W $P_2 = V_2 I_2 = +810$ W

Using KCL/KVL in problem solving

- ❑ Identify unknowns
- ❑ Label each current and assign a direction to it. Then, identify the polarity of each voltage
- ❑ Choose the nodes and closed paths
- ❑ Apply KCL to nodes and KVL to closed paths. **Remember:** the number of independent equations must match the number of unknown
- ❑ Solve the equations

Resistance in electronic components

Band Color	Digit	Multiplier	Tolerance
Black	0	1	---
Brown	1	10	±1%
Red	2	100	±2%
Orange	3	1,000	±3%
Yellow	4	10,000	±4%
Green	5	100,000	---
Blue	6	1,000,000	---
Violet	7	10,000,000	---
Gray	8	100,000,000	---
White	9	---	---
Gold	---	0.1	±5%
Silver	---	0.01	±10%
None	---	---	±20%

- Resistors are made as small electronic components
- The resistance of the component is reported on the case by using bands of different color (color code)

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- On a resistor, four color bands encode the resistance

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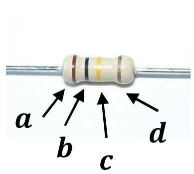

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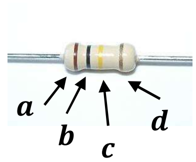
- The resistance is read as:

  $R = ab \times 10^c\ \Omega$



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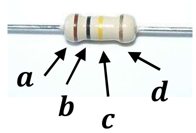
- The tolerance is:

  $\pm\ 100d\%$



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- In figure:

  $R = 10 \times 10^4\ \Omega$
- The tolerance is:

  $\pm\ 10\%$