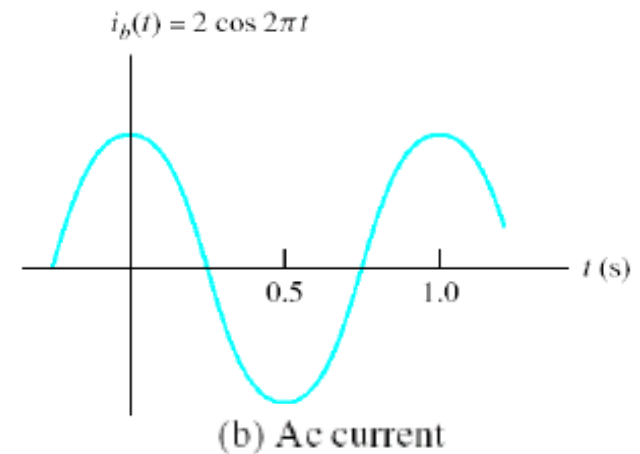
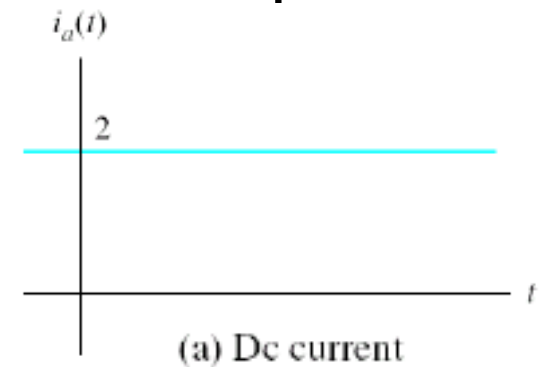


# Course Outline

Block A is your introduction and gateway into electrical engineering. It focuses on the most basic concepts of electrical engineering.

- Block A – Direct Current (DC)
- Block B – Alternating Current (AC)
- Block C – Operational Amplifier
- Block D – Semiconductors and diodes



# Block A Unit 1

---

- Block A Unit 1 is organized into 4 sections. These four sections cover the 3 basic laws in circuits:
  - I. Kirchhoff's Current, Voltage Law, Ohm's Law, and Electrical Power
  - II. Sources, Short Circuit, Open Circuit
  - III. Resistive Networks
  - IV. Measuring Instruments

Alexander & Sadiku, “Fundamentals of Electric Circuits” , 7<sup>th</sup> Edition, McGraw Hill, Ch 1 & 2

# I. Current and Kirchhoff's Current Law

---

- Charge is a fundamental electrical quantity
- Typically denoted by the symbol  $Q$ , and its SI unit is the Coulomb (C)
- The smallest amount of charge that exists is the charge that is carried by an electron:

$$Q_e = 1.602 \times 10^{-19} \text{ C}$$

**Always include units, otherwise there is no meaning**

# Current: Free electrons on the move

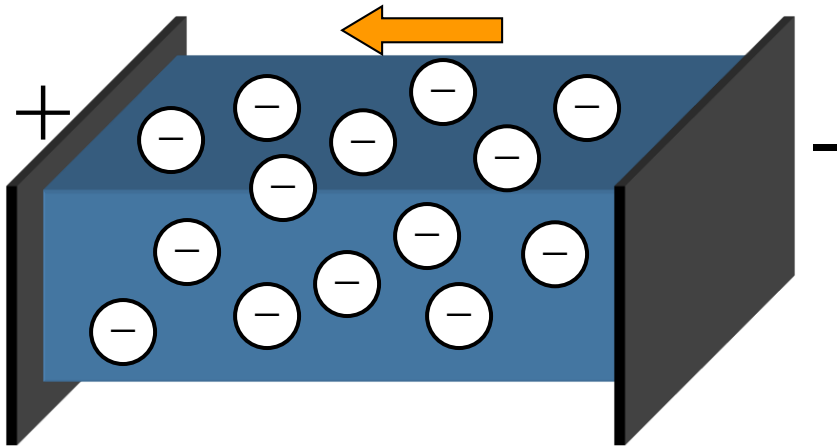


Fig 1a. A voltage is applied to move the charges

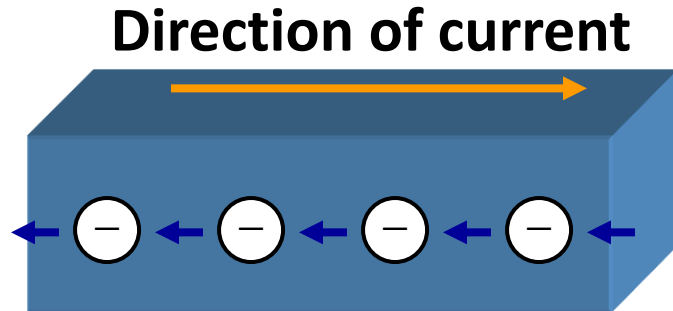


Fig 1b. Movement of electrons gives rise to current

**Key Concept 1**  
**For current to flow, there must be mobile charges**

- Direction of electron flows is from negative to positive
- Direction of current flows (positive charges) is from positive to negative
- Typically denoted by the symbol,  $I$
- SI unit is the Ampere (A)

# Current must run in loops

- If a current flows out of a given point, then it must return to that point with the same amount
- Current must flow in loops
- What goes around comes around

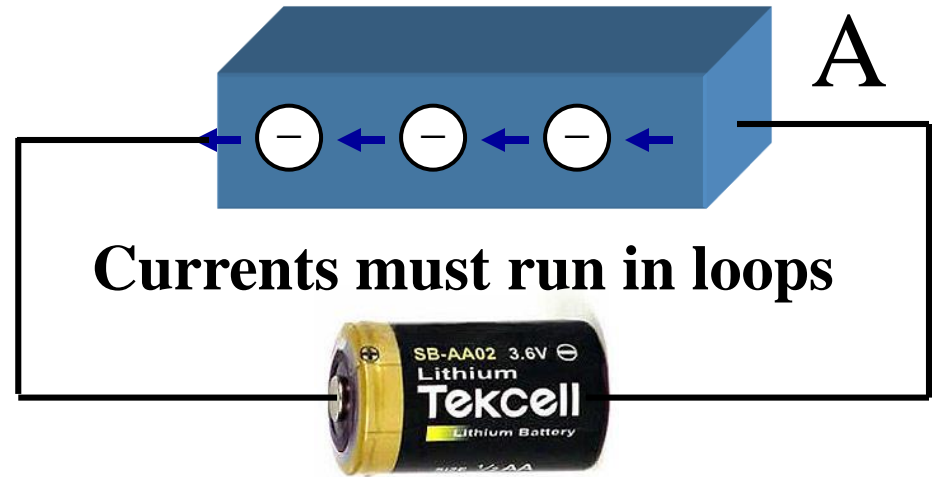


Fig 2. Current must run in loops

## Key Concept 2

**Currents must run in loops (otherwise charge is either destroyed or created which cannot happen)**

# Fundamental law for charge

- Current has to flow in closed loop
- No current flows if there is a break in the path
- Underlying physical law: Charge cannot be created or destroyed (“what goes in must also come out”)
- This is the basis of Kirchhoff’s Current Law

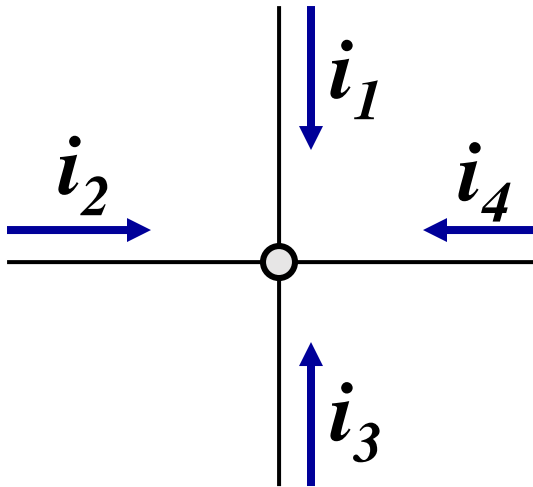


Fig 3.

## Kirchhoff's current law

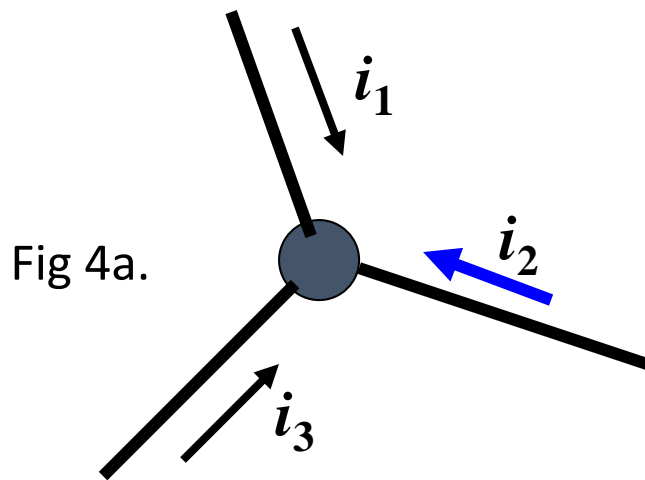
Sum of currents at a node must equal to zero:

$$i_1 + i_2 + i_3 + i_4 = 0$$

# Kirchhoff's current law

Does the direction of current matter? **YES!!**

$I_2$  running into node



$$i_1 + i_2 + i_3 = 0$$

$I_2$  running out of node

Different

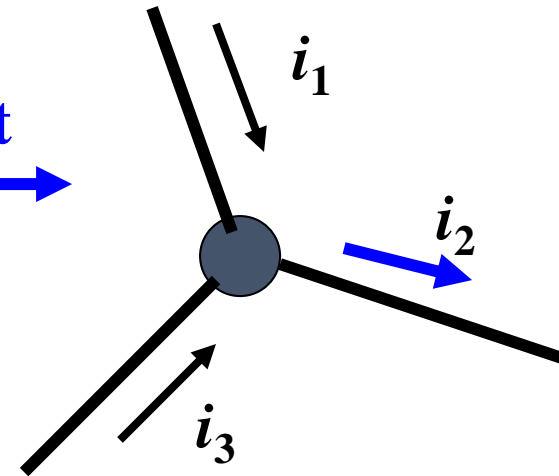


Fig 4b.

$$i_1 + i_2 + i_3 = 0 \text{ (WRONG)}$$

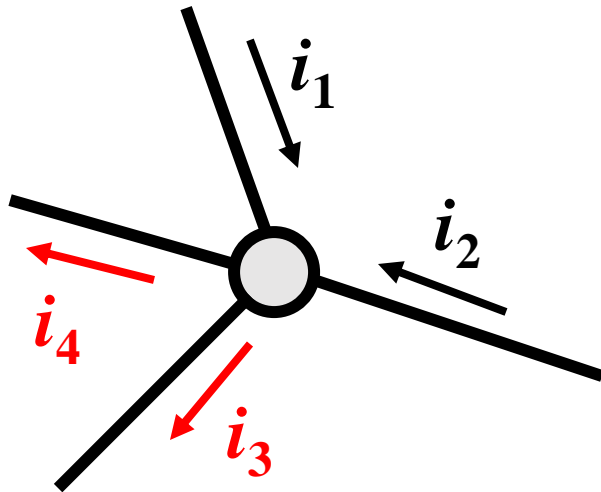
$$i_1 + i_3 = i_2 \text{ (CORRECT)}$$

# Kirchhoff's current law

## Sign convention when applying KCL

Currents flowing IN - Positive

Currents flowing OUT - Negative



Entering:  $I_1$  &  $I_2$  (+ve)

Exiting:  $I_3$  &  $I_4$  (-ve)

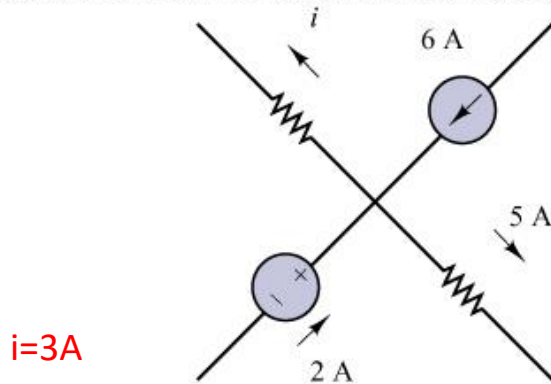
$$i_1 + i_2 - i_3 - i_4 = 0$$



# Worked Example on KCL

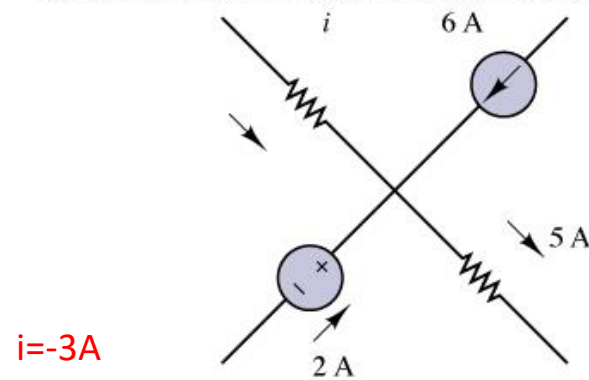
Find the unknown current within each of the following circuit networks

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$$i=3A$$

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$$i=-3A$$

# Voltage and Kirchhoff's Voltage Law

- Energy is required to move electrons between 2 points
- This energy could come from the battery cell connected to the circuit
- As the current goes across the cell, energy is pumped in
- As the current goes through a light bulb, energy is consumed
- The amount of energy required to move a unit charge is given by the voltage
- SI unit is Voltage (V)

## Potential Difference

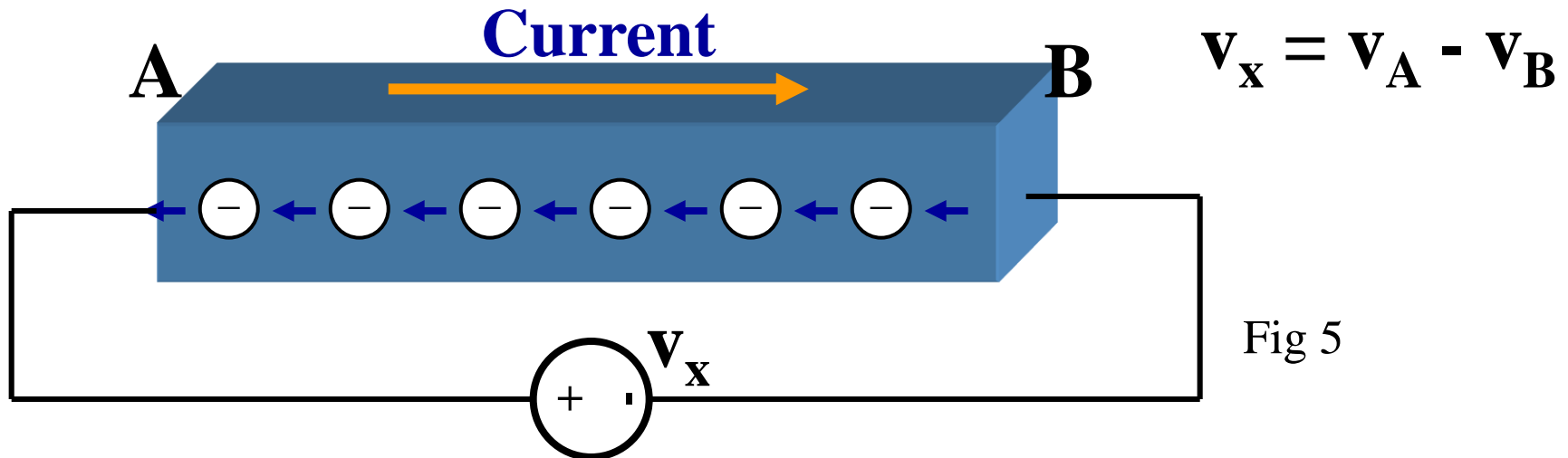


Fig 5

# Sign Convention

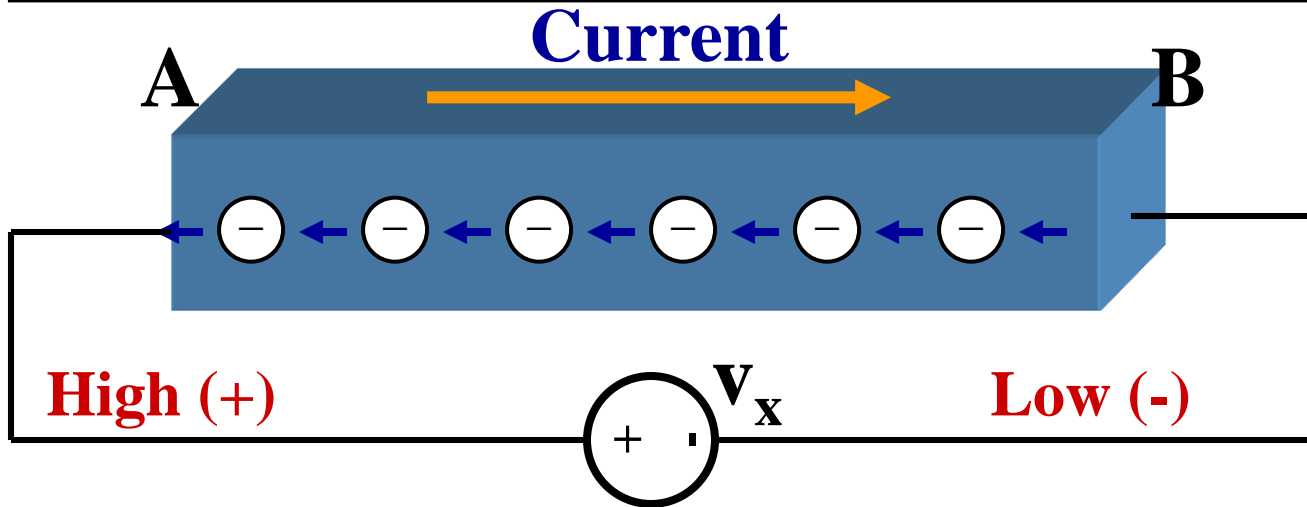


Fig 6

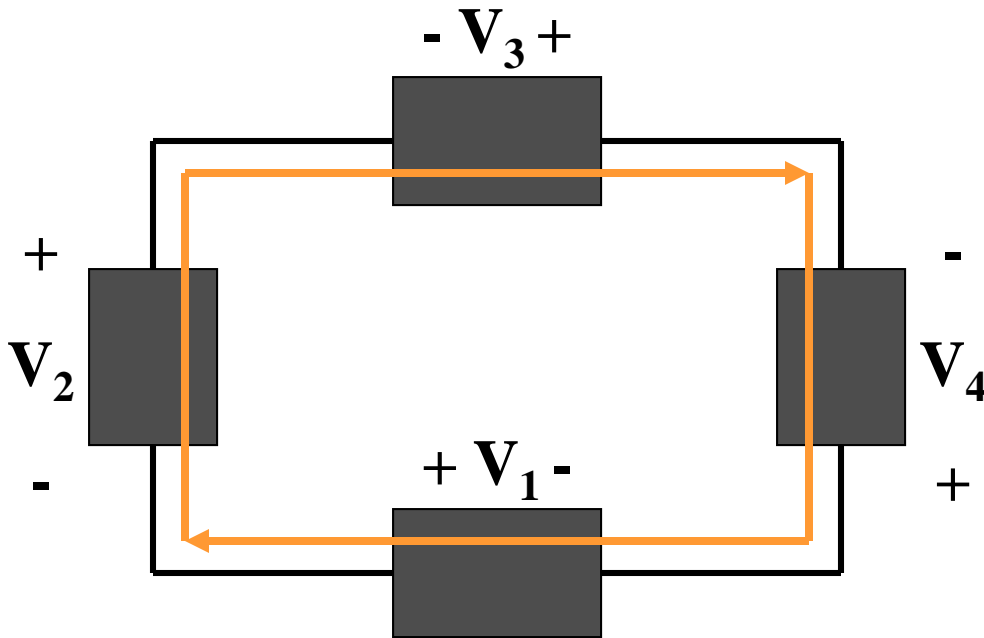
## Sign Convention for Voltage

Voltage rises (negative to positive) along the direction of the current for an element that is generating power

Voltage drops (positive to negative) along the direction of the current for an element that is consuming power

# Kirchhoff's Voltage Law (KVL)

- KVL states that the sum of voltages around a loop must equal to zero
- If a voltage starts at any given point, no gain or loss of any voltage when it returns to the same point
- Whatever energy is pumped into the loop must also be consumed



## Kirchhoff's voltage law

Net voltage around a closed circuit is zero:

$$v_1 + v_2 + v_3 + v_4 = 0$$

Fig 7: Voltages around a closed loop

# Kirchhoff's voltage law

- First, you need to define the direction
  - $V_1$  and  $V_3$  are voltage rises (positive) while  $V_2$  is a voltage drop (negative)
  - In the other direction,  $V_2$  is voltage rise (positive), while  $V_1$  and  $V_3$  are voltage drops (negative)
- $$V_2 - V_1 - V_3 = 0$$

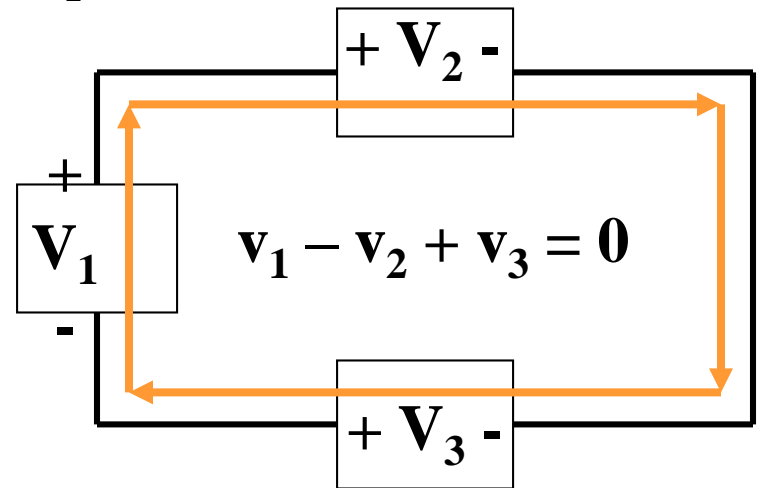


Fig 8: Defined voltage drops and rises

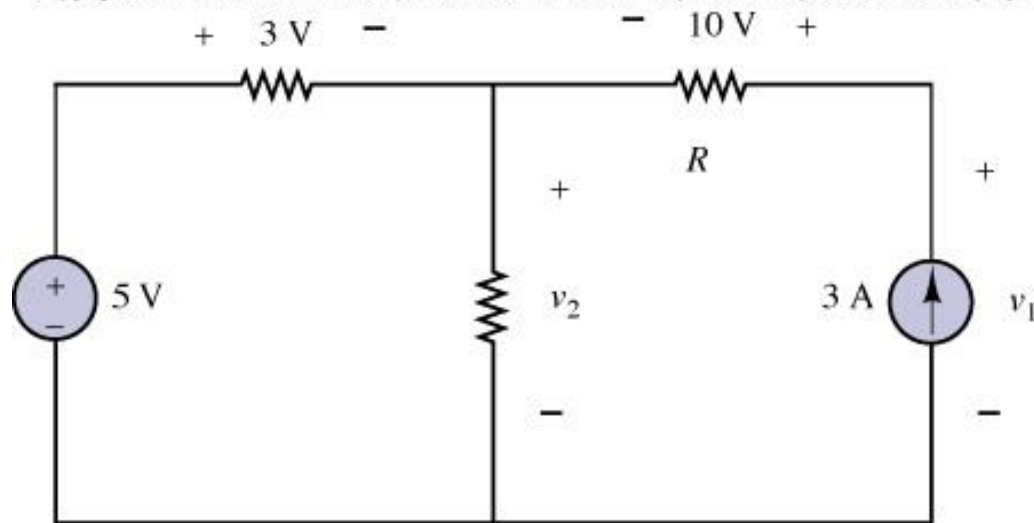
**Sign Convention for KVL**  
Voltage RISE – Positive  
Voltage DROP – Negative

# Worked Example on KVL

Apply KVL to find voltage  $V_1$  and  $V_2$

$$V_1 = 12V, V_2 = 2V$$

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# Resistance and Ohm's Law

- When current flows through a conductor, it will always experience some resistance
- Resistance is given by the change in voltage over change in current
- SI unit is Ohm ( $\Omega$ )
- If the voltage is linear with current, then resistance is said to be linear and obeys Ohm's law

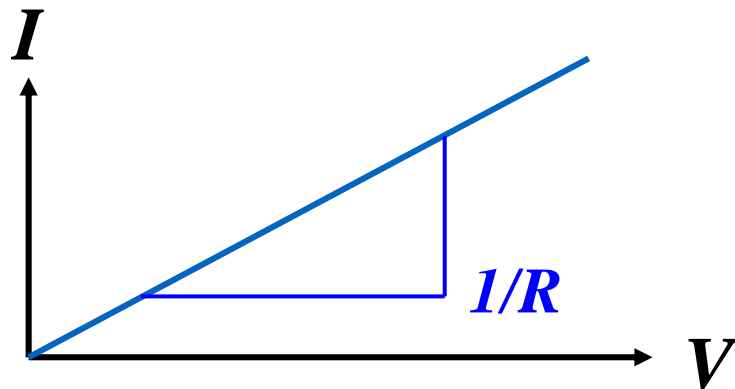


Fig 9a: Linear resistance that obeys Ohm's law

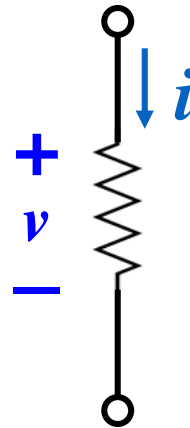


Fig 9b

Ohm's law is given as:

$$V = IR$$

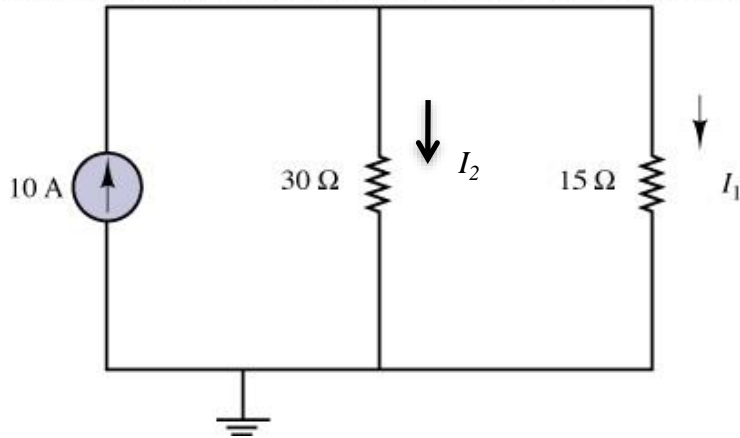
Important point to note:

**If an unknown current is defined to flow from A to B, the voltage at A is assumed to be higher than B.**

# Worked Examples Applying 3 Laws

Find the current through the  $15\Omega$  resistor  $I_1 = 6.67\text{A}, I_2 = 3.33\text{A}$

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# Electrical Power

- A voltage drop in the direction of the current indicates the power is consumed
- Conversely, a voltage rise in the direction of the current indicates that power is generated
- If the voltage across a resistor is  $V$ , and current through it is  $I$ , then the power consumed is given by:

$$P = VI$$

$$\text{Ohm's law} \rightarrow P = I^2 R$$

$$\text{Ohm's law} \rightarrow P = V^2 / R$$

Power generated by source

**MUST EQUAL**

Power dissipated in the load

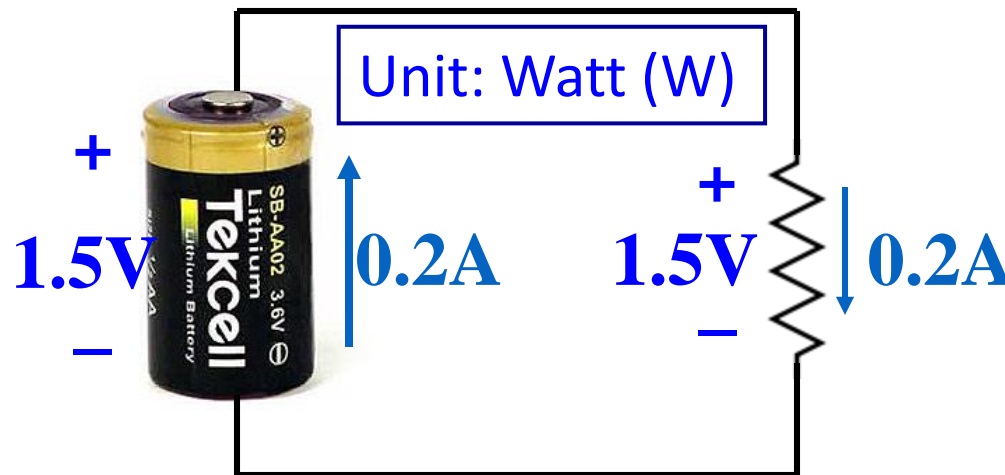
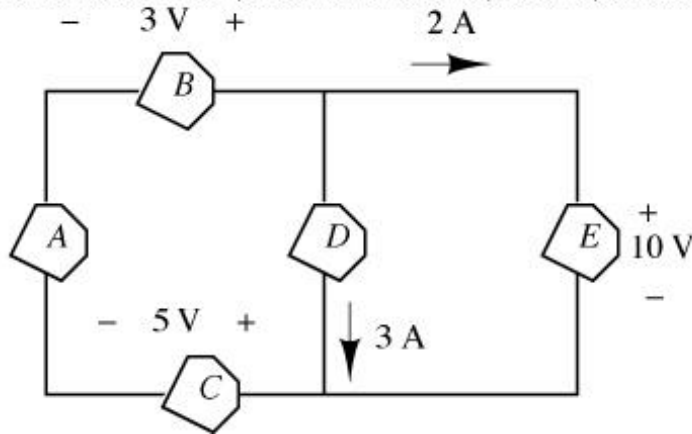


Fig 10: Power generated and consumed in a circuit

# Worked Example on Power

Determine which components are absorbing power and which are delivering power

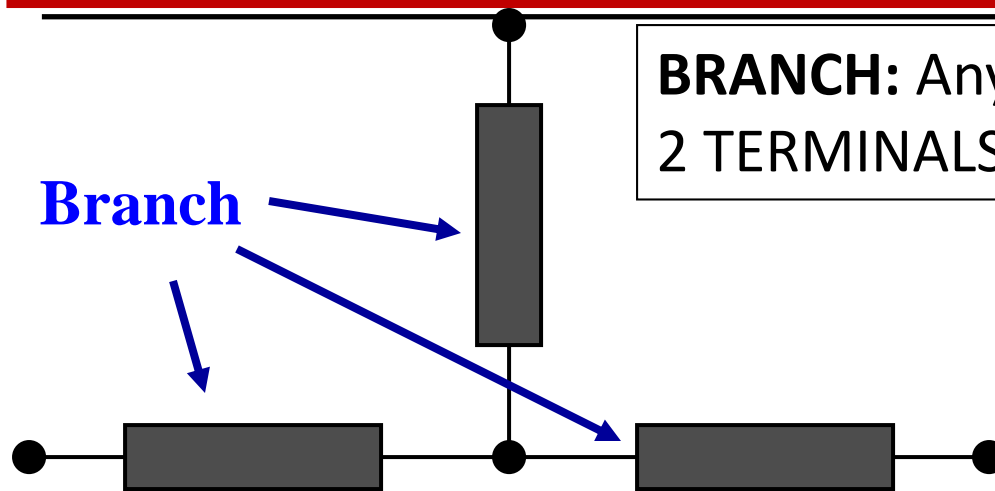
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Delivering: A (60W), B (15W)

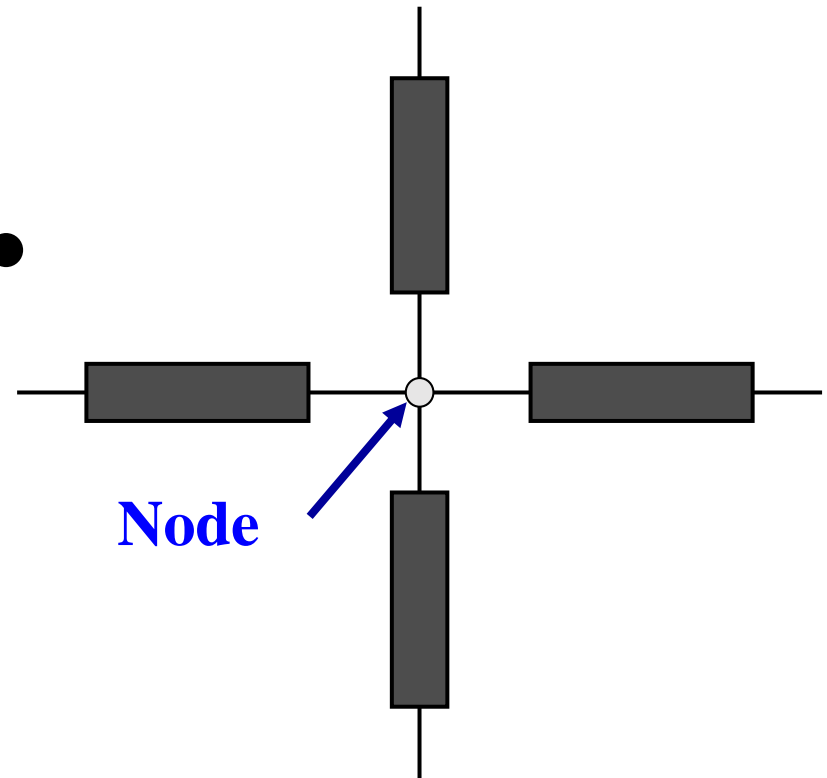
Consuming: C (25W), D (30W), E (20W)

# Terminology: Branch and Node



**BRANCH:** Any path of a circuit with 2 TERMINALS connected to it

Fig 11a: 3 branches



**NODE:** Junction of 2 or more branches

Fig 11b: 1 node

# Terminology: Loop and Mesh

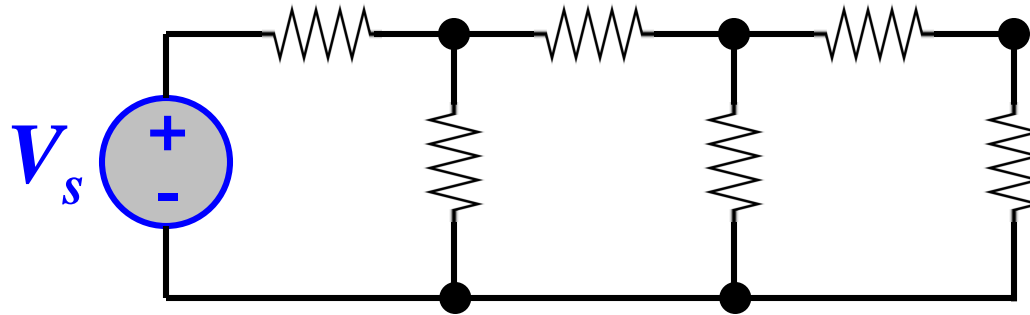


Fig 12: Loops (6) and meshes (3)

- **Loop:** Any closed connection of branches
- **Mesh:** Loop that does not contain any loops
- In Fig 12, there are 6 loops and 3 meshes.
- We will use the term mesh more than loop in this course

## II. Sources, Short Circuit and Open Circuit

- Loads (e.g. resistors) consume power
- Sources on the other hand deliver power

### Ideal Voltage Source

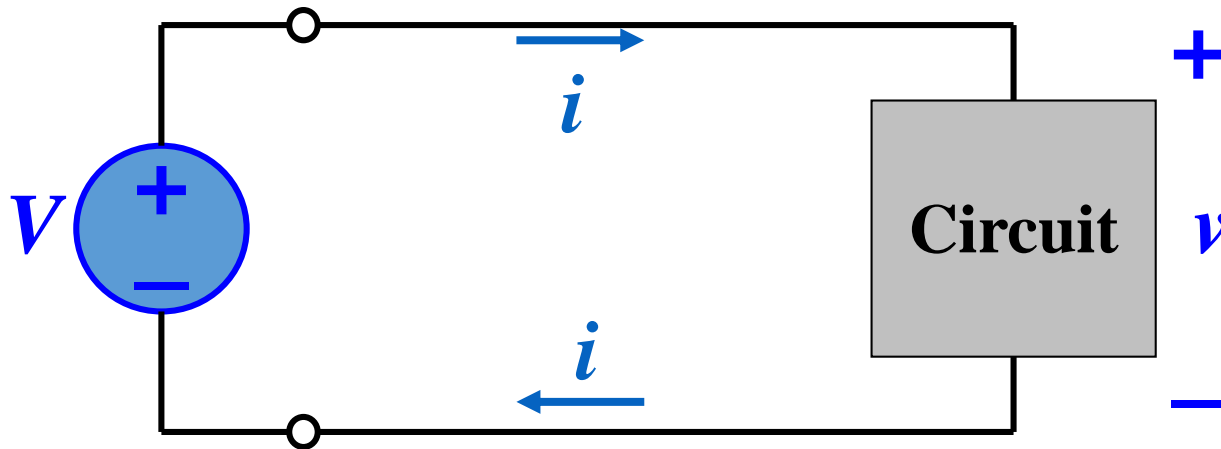


Fig 13a: Ideal voltage source in a circuit

- The purpose of a voltage source is to keep the voltage across its terminals unchanged
- Current through a voltage source is allowed to change in order to maintain the voltage at  $V$  with reference to Fig 13a

# Ideal Current Source

## Ideal Current Source

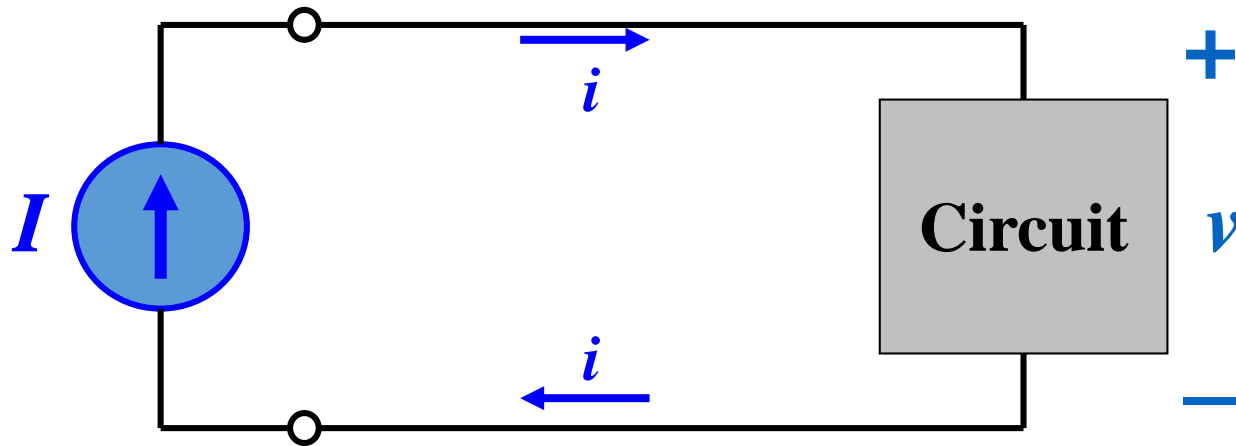


Fig 13b: Ideal current source in a circuit

- The purpose of a current source is to keep the current flowing through it unchanged
- Voltage across a current source is allowed to change in order to maintain the current at  $I$  with reference to Fig 13b

**Recognize the differences between an ideal voltage and current source in their functions and symbols.**

# Short Circuit

- A short circuit means connecting 2 or more terminals together so that the voltage between them is zero
- It is typically associated with currents rather than voltage, e.g. short circuit current

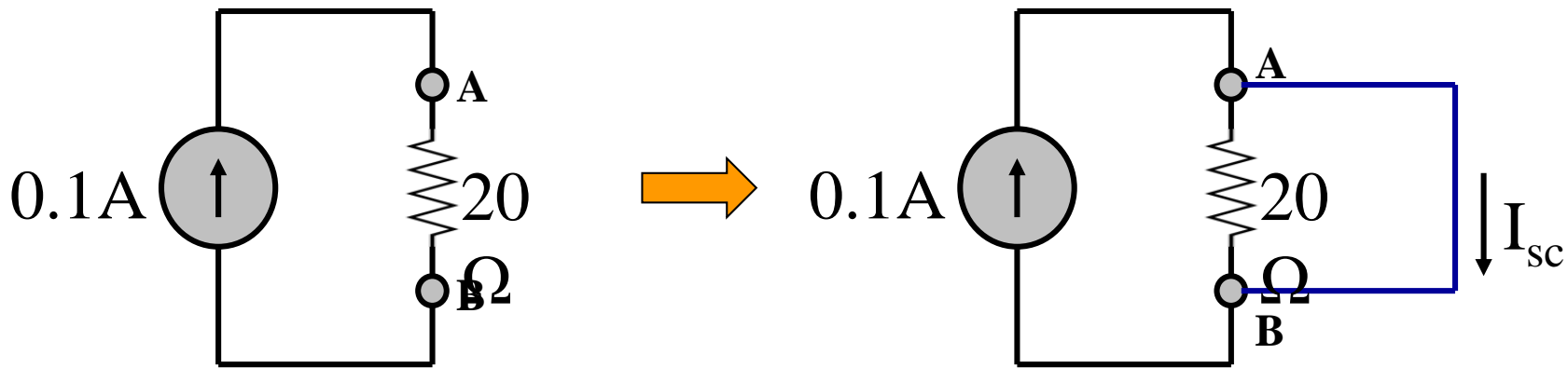


Fig 14a: Short circuiting the resistor

- All the current from the source flows through the short circuit, bypassing the resistor
- Short circuit current  $I_{sc} = 0.1 \text{ A}$

# Open Circuit

- An open circuit means no extra connections are imposed across two terminals
- It is typically associated with voltage rather than current, e.g. open circuit voltage

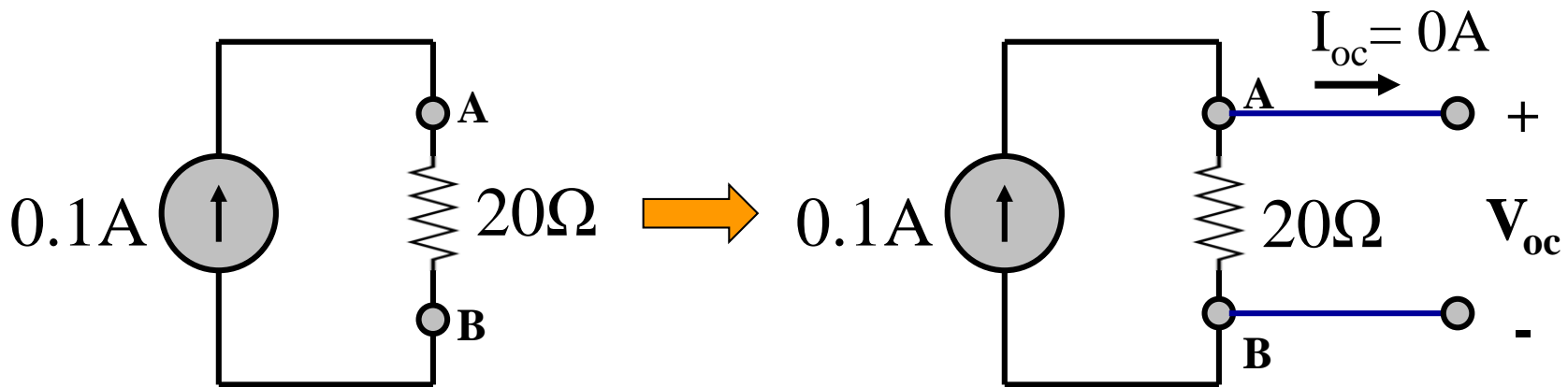


Fig 14b: Open circuiting the resistor

- In Fig 14b, the open circuit voltage of the resistor is simply the voltage across the resistor
- Open circuit Voltage  $V_{oc} = 2\text{ V}$



# Prefixes

- As engineers, it is important that we replace exponents with prefixes
- For example:  
0.00215 A  $\rightarrow$  2.15 mA  
never  $2.15 \times 10^{-3}$  A
- Make sure you memorize the prefixes from nano (n) to mega (M)

Prefixes: Memorize and **apply** them!

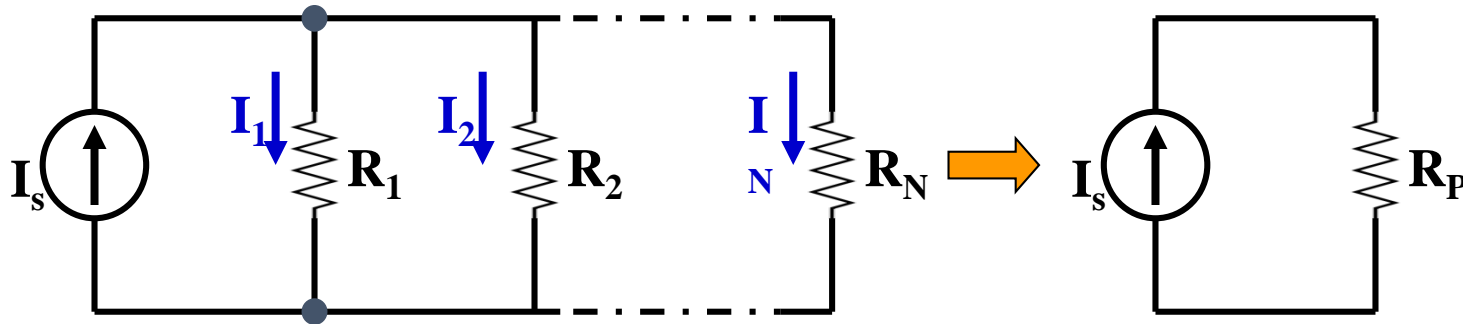
tera	T	$10^{12}$
giga	G	$10^9$
mega	M	$10^6$
kilo	k	$10^3$
milli	m	$10^{-3}$
micro	$\mu$	$10^{-6}$
nano	n	$10^{-9}$
pico	p	$10^{-12}$
femto	f	$10^{-15}$

# III. Resistive Networks

- Resistors are either arranged in parallel or in series or as combination of both

## Parallel Network

Fig 15a: Parallel resistive network



Equivalent Resistance  $R_P$ :

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_N}$$

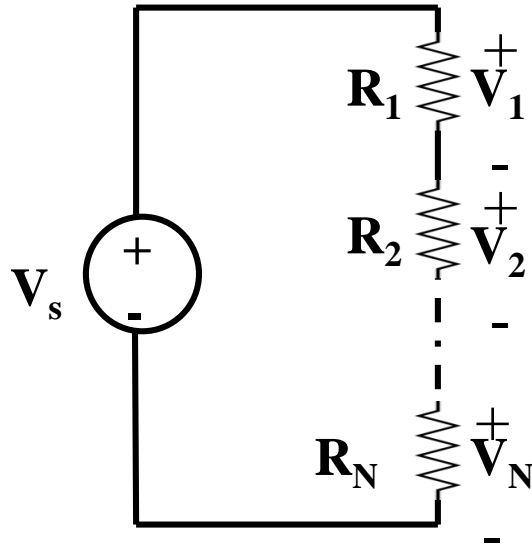
## Current Divider Rule

$$I_k = \frac{R_P}{R_k} I_s$$

- Current ( $I_s$ ) from the source will have to be shared between the resistors ( $R_k$ ) in each branch

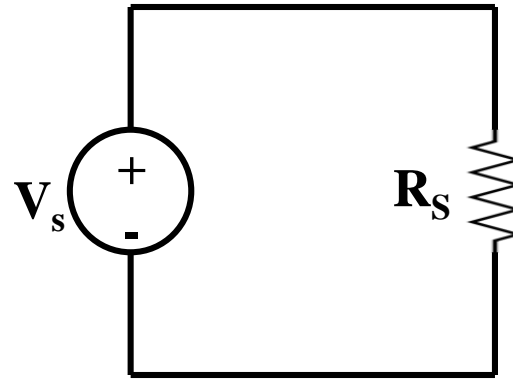
# Series network (Highlights)

## Series Network



Equivalent Resistance  $R_p$ :

Fig 15b: Series resistive network



$$R_S = R_1 + R_2 + \dots + R_N$$

## Voltage Divider Rule

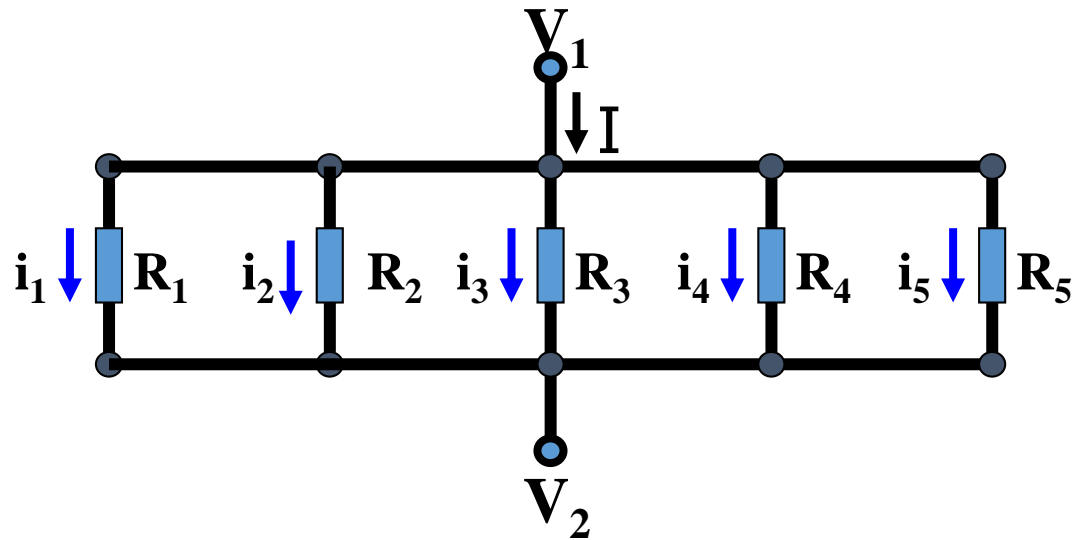
$$V_k = \frac{R_k}{R_S} V_S$$

- Total voltage drop across all the resistors ( $V_s$ ) in series is the sum total of voltage ( $V_k$ ) drops across each resistor

# Worked Example on Current Divider Rule

Rank the currents from largest to smallest if  $R_2 > R_4 > R_1 > R_5 > R_3$

$$I_3 > I_5 > I_1 > I_4 > I_2$$

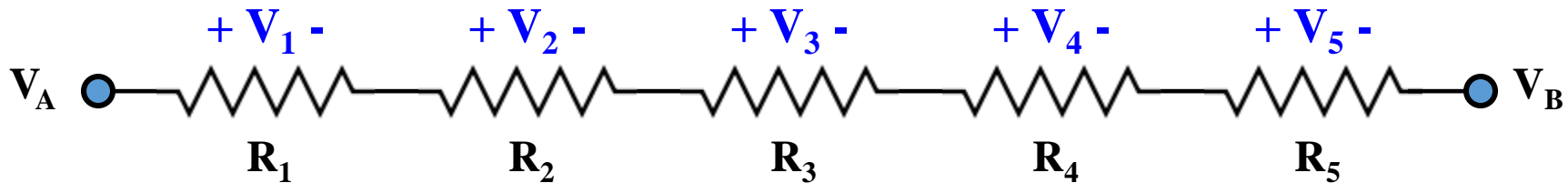


# Worked Example on Voltage Divider Rule

Rank the potential difference from largest to smallest

if  $R_2 > R_4 > R_1 > R_5 > R_3$

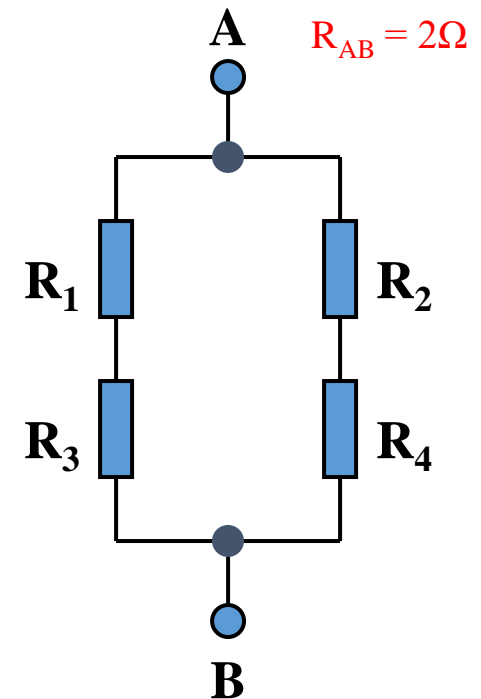
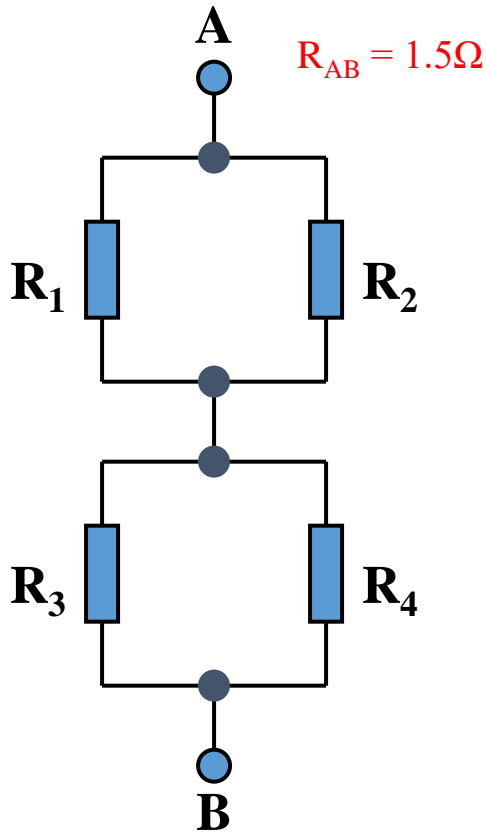
$$V_2 > V_4 > V_1 > V_5 > V_3$$



# Worked Example 1 on Resistive Networks

Find the effective resistance across A and B

$$R_1 = R_4 = 1\Omega, R_2 = R_3 = 3\Omega$$



# Worked Example 2 on Resistive Networks

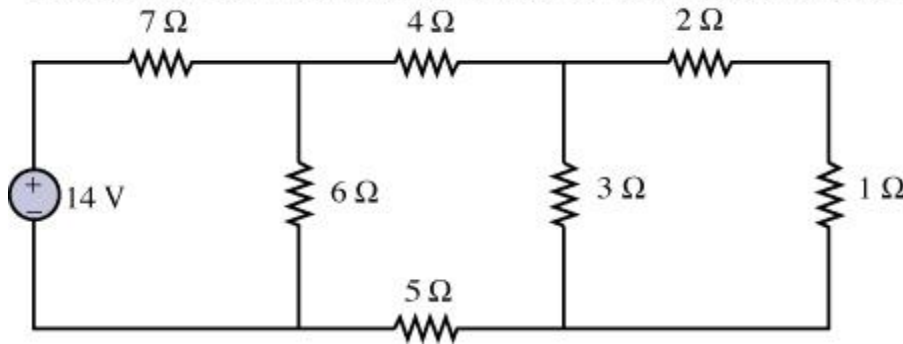
What is the equivalent resistance seen by the source?

$$R_{eq} = 10.818 \, \Omega$$

What is power supplied by the source?

$$P = 18.1 \, \text{W}$$

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# IV. Measuring Instruments - Voltmeter

- Voltmeter measures voltage across a circuit element



Fig 16: Image of typical voltage with a measuring range up to 30V

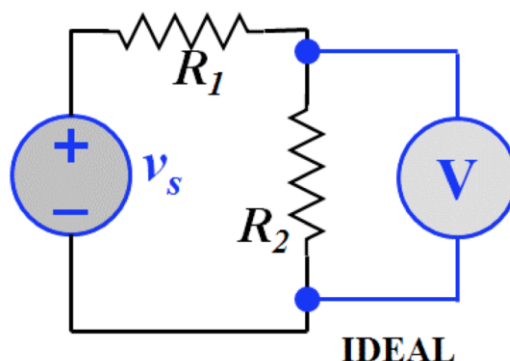


Fig 17a: Placement of an ideal voltmeter to measure the PD across  $R_2$

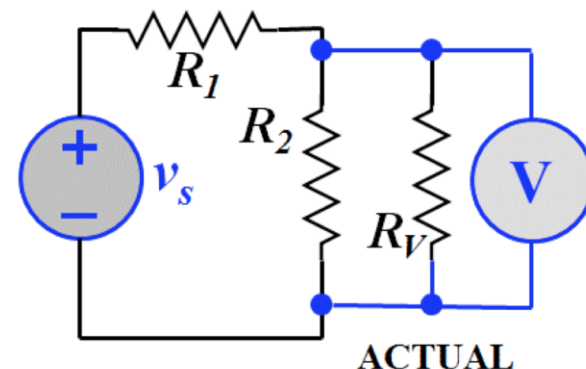


Fig 17b: Circuit model of how a real voltmeter behaves, which looks like a large parallel resistor ( $R_V$ )

## How would you place the voltmeter in the circuits?

- Connected in **parallel** with the element being measured

In Fig 17a, voltmeter has no effect on original circuit.

In Fig 17b, voltmeter will steal current from  $R_2$ . This will change the voltage measured across  $R_2$ . Thus, the PD measured with a voltmeter is lower than the true value.



# Worked Example on Voltmeters

Referring to Fig 17b, if  $V_s = 5V$ , and  $R_V = 1M\Omega$ ,  
find the voltage across  $R_2$  when

(i)  $R_1 = R_2 = 1k\Omega$        $V = 2.5V$

(ii)  $R_1 = R_2 = 1M\Omega$        $V = 1.67V$

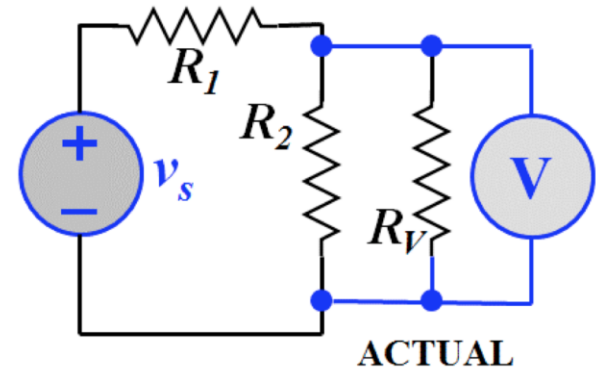


Fig 17b

# Ammeter

- Ammeter measures current



Fig 18: Image of typical current with a measuring range up to 20A

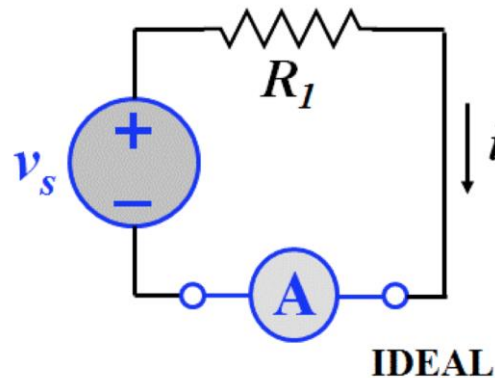


Fig 19a: Placement of an ideal ammeter to measure current through  $R_1$

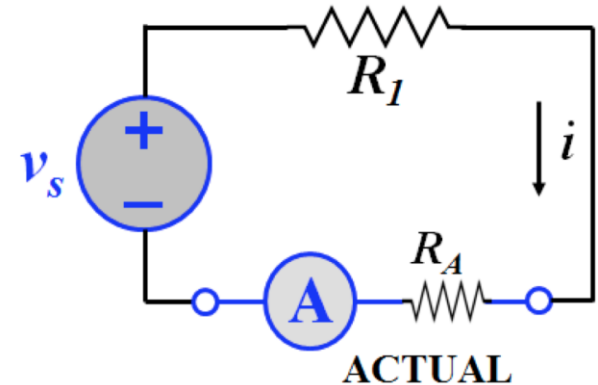


Fig 19b: Circuit model of how a real ammeter behaves, which looks like a small series resistor ( $R_A$ )

## How would you place the ammeter in the circuits?

- Connected in **series** with the element being measured

In Fig 19a, ammeter has no effect on original circuit.

In Fig 19b, ammeter contains some resistance ( $R_A$ ), adding to the total resistance, lowering the measured current. **Thus, the current measured with an ammeter is lower than the true value.**

# Ammeter Example

Referring to Fig 19b, if  $V_s = 5V$ , and  $R_A = 1\Omega$ ,  
find the loop current when

(i)  $R_1 = 1k\Omega$       $I = 4.995 \text{ mA}$

(ii)  $R_1 = 2\Omega$       $I = 1.33A$

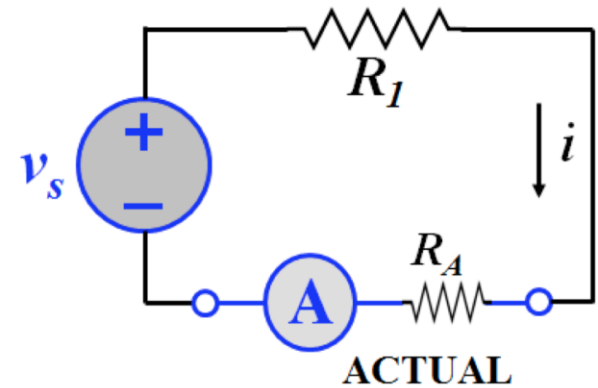


Fig 19b