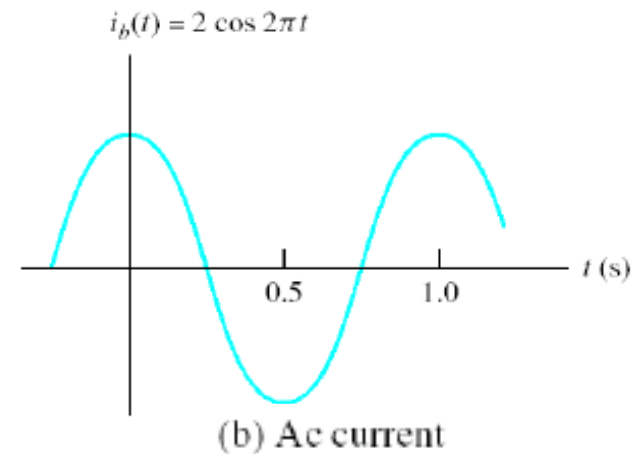
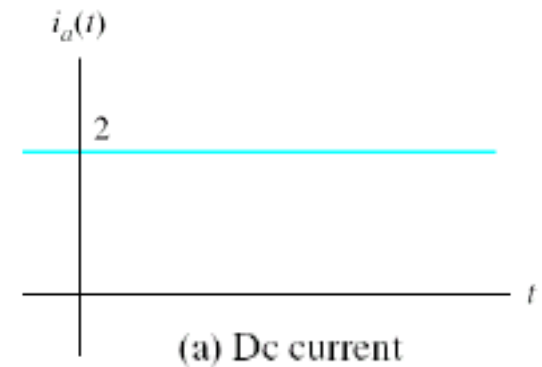


# Course Outline

This revision unit is your introduction and gateway into electrical engineering. It focuses on the most basic concepts of electrical engineering.

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



# Revision on DC

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- This revision is organized into 7 sections. The first four sections cover the 3 basic laws in circuits:
  - I. Kirchhoff's Current, Voltage Law, and Ohm's Law
  - II. Sources, Short Circuit, Open Circuit
  - III. Resistive Networks
  - IV. Measuring Instruments
- It is important to apply the 3 basic laws in circuit theory to analyze and design circuits
  - V. Nodal Voltage Analysis, Mesh Current Analysis, Superposition
  - VI. Thevenin Equivalent Circuit, Norton Equivalent Circuit, Source Transformation

Alexander & Sadiku, "Fundamentals of Electric Circuits" , 7<sup>th</sup> Edition, McGraw Hill

# Revision on DC (Part I)

---

- I. Kirchhoff's Current, Voltage Law, and Ohm's Law
- 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

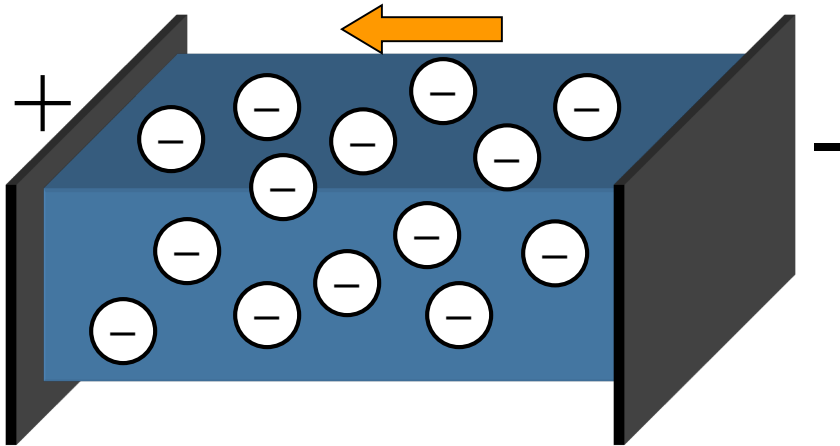
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- Charge is a fundamental electrical quantity
- Typically denoted by the symbol  $Q$ , and its SI unit is the Coulomb (C)
- The smallest amount of charge that exists is the charge that is carried by an electron:

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

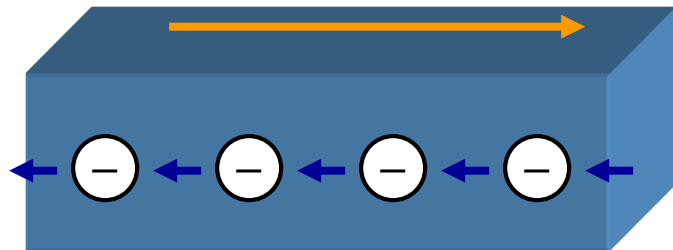
**Always include units, otherwise there is no meaning**

# Current: Free electrons on the move



A voltage is applied to move the charges

## Direction of current



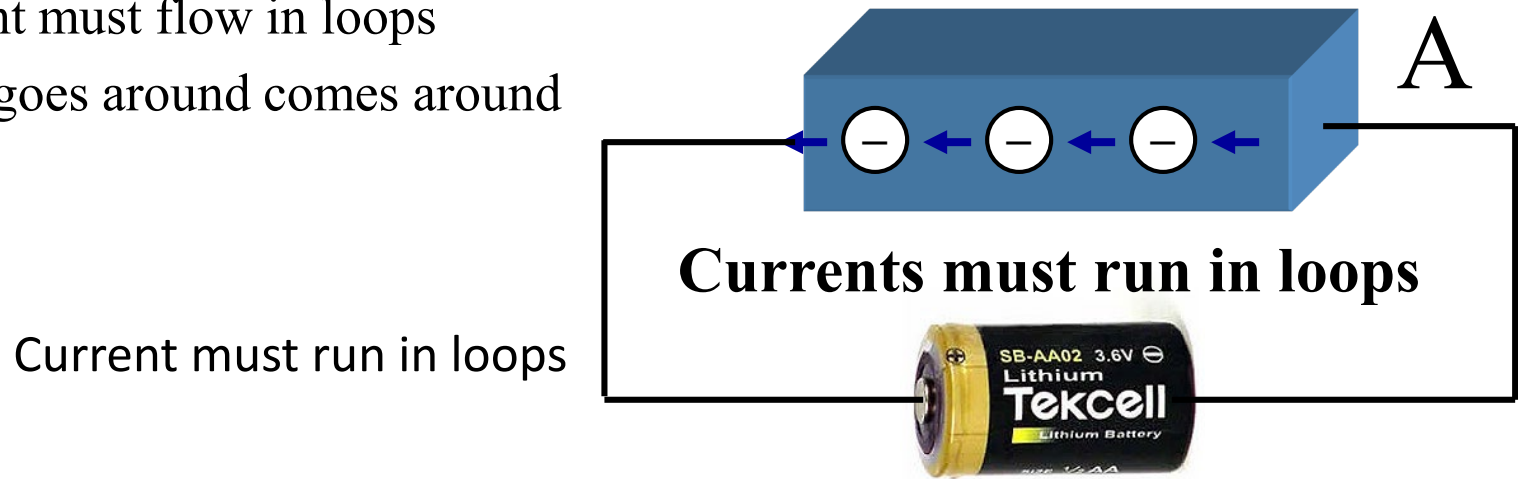
Movement of electrons gives rise to current

**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

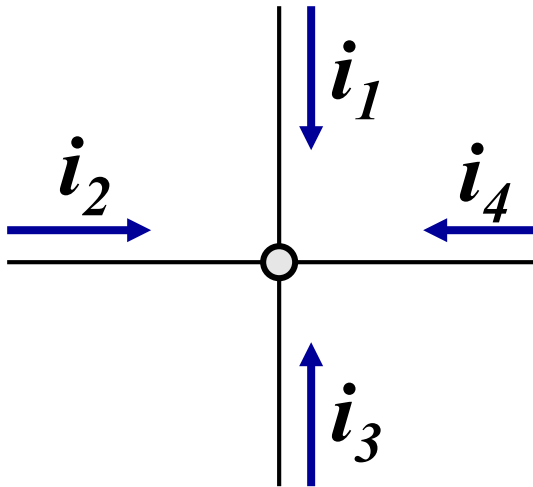


## Key Concept 2

**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



## Kirchhoff's current law

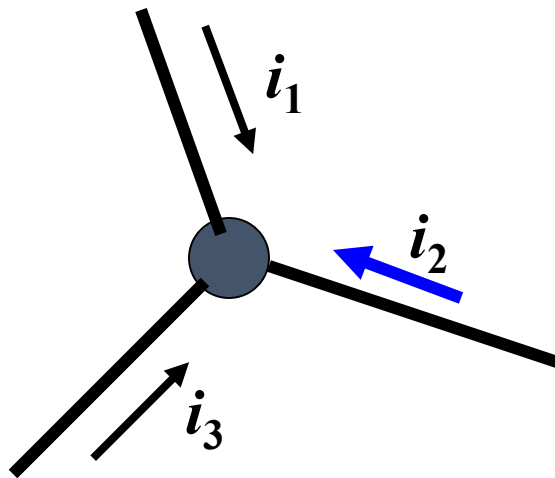
Sum of currents at a node must equal to zero:

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

# Kirchhoff's current law

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

$I_2$  running into node

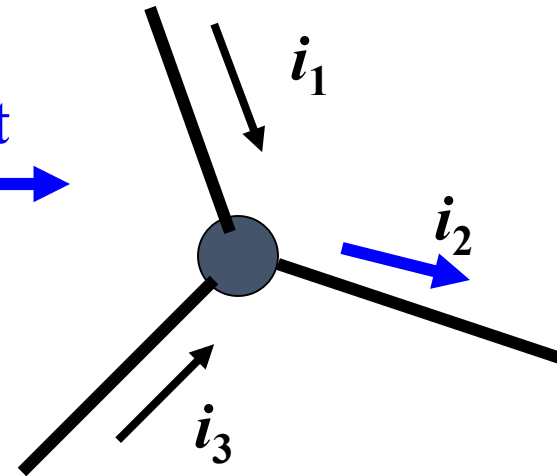


$$i_1 + i_2 + i_3 = 0$$

Different



$I_2$  running out of node

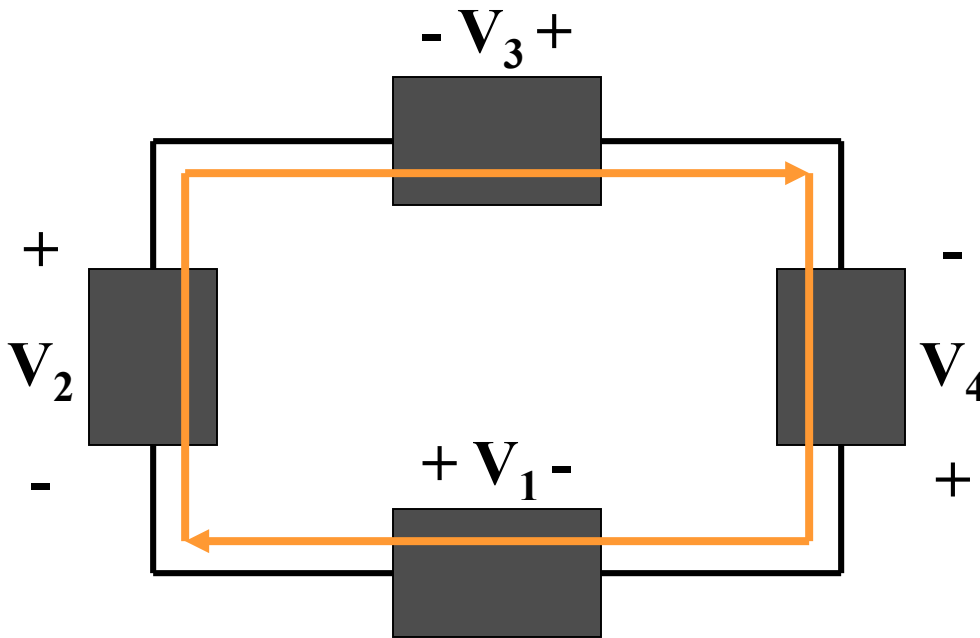


$$i_1 + i_2 + i_3 = 0 \text{ (WRONG)}$$

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

# 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



Voltages around a closed loop

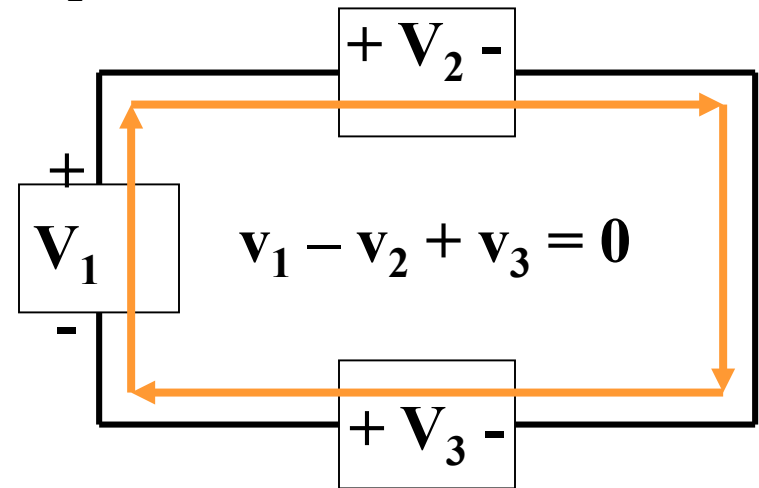
## Kirchhoff's voltage law

Net voltage around a closed circuit is zero:

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

# 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)
- $$V_2 - V_1 - V_3 = 0$$



Defined voltage drops and rises

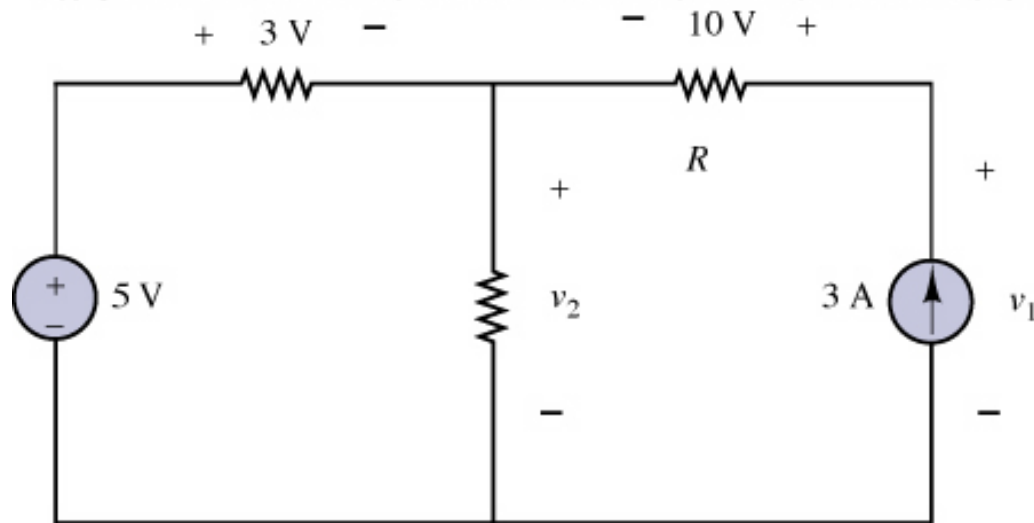
**Sign Convention for KVL**  
Voltage RISE – Positive  
Voltage DROP – Negative

# Worked Example on KVL

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

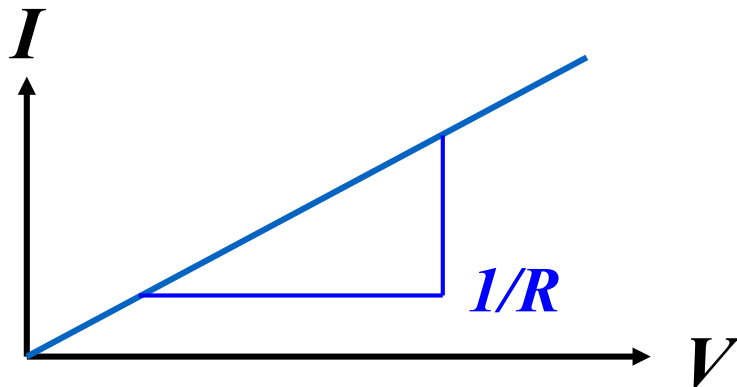
$$V_1 = 12\text{V}, V_2 = 2\text{V}$$

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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



Linear resistance that obeys Ohm's law

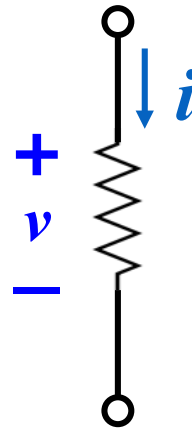


Fig 5b

Ohm's law is given as:

$$V = IR$$

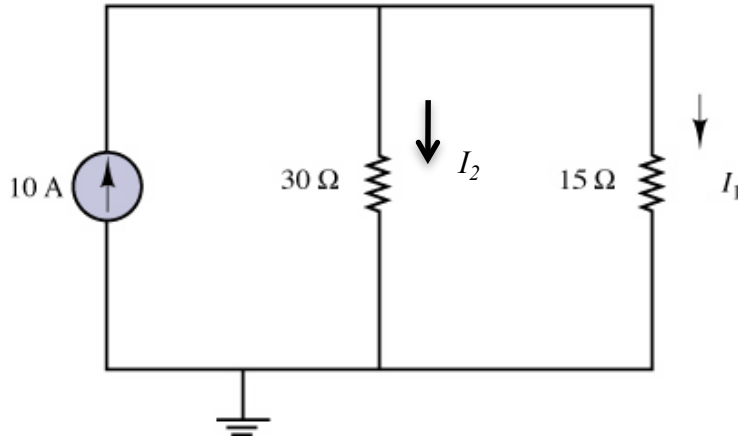
Important point to note:

**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:

$$P = VI$$

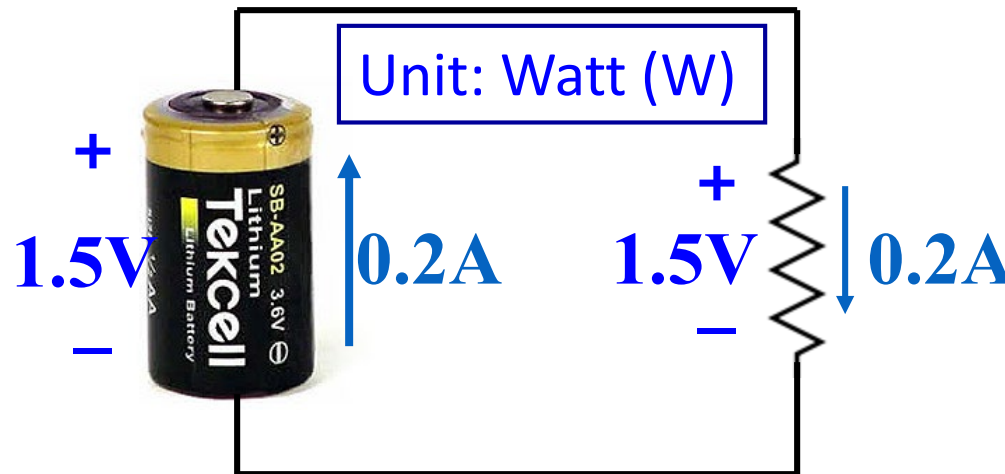
$$\text{Ohm's law} \rightarrow P = I^2 R$$

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

Power generated by source

**MUST EQUAL**

Power dissipated in the load

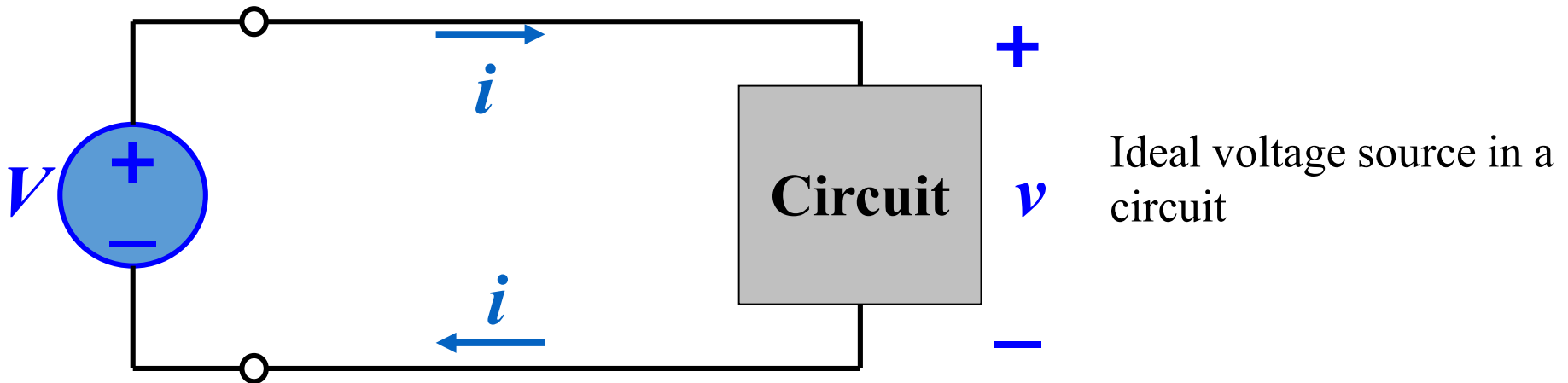


Power generated and consumed in a circuit

# II. Sources, Short Circuit and Open Circuit

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

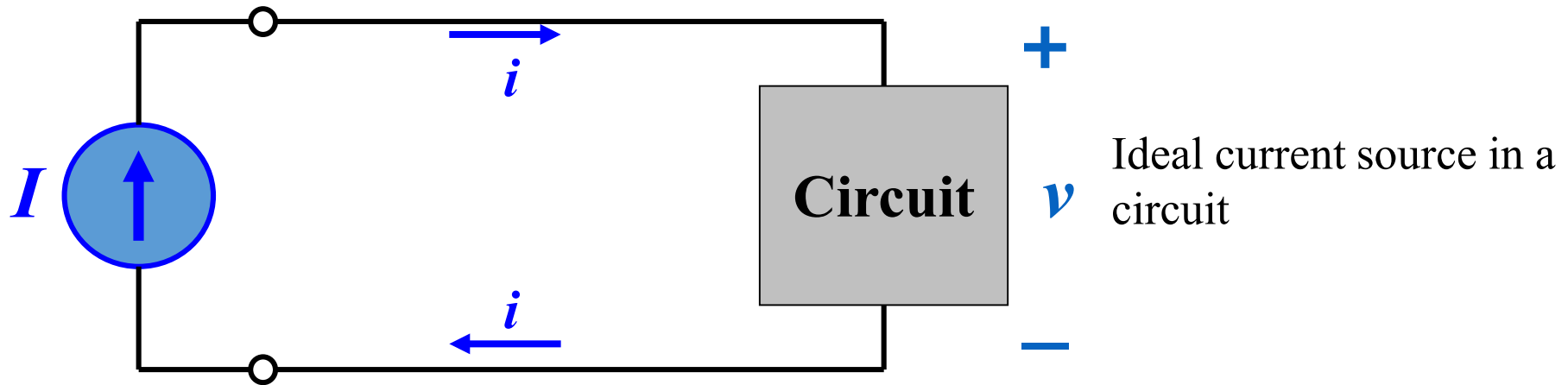
## Ideal Voltage Source



- 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 the Figure

# Ideal Current Source

## Ideal Current Source

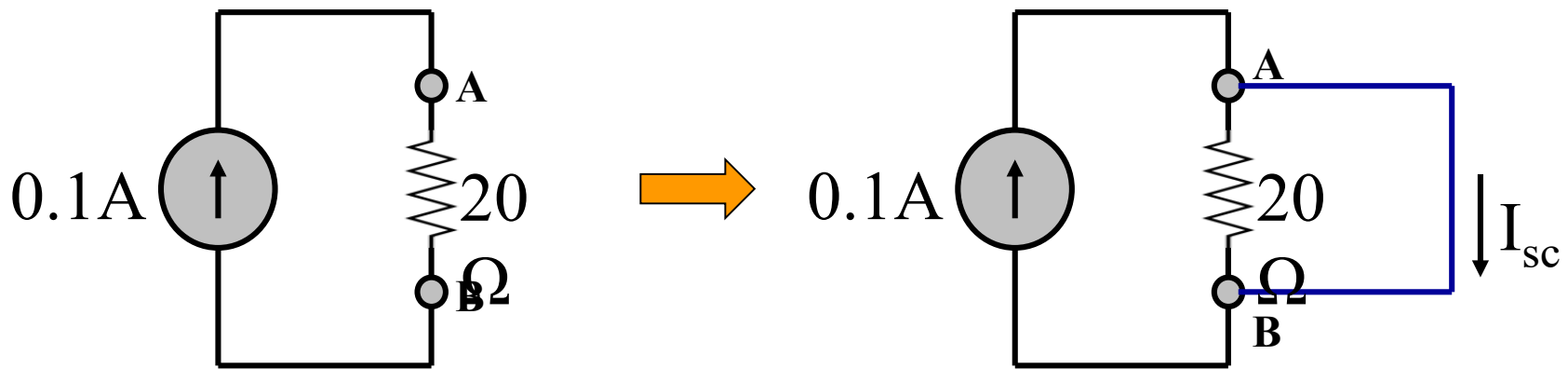


- The purpose of a current source is to keep the current flowing through it unchanged
- Voltage across a current source is allowed to change in order to maintain the current at  $I$  with reference to the Figure

**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

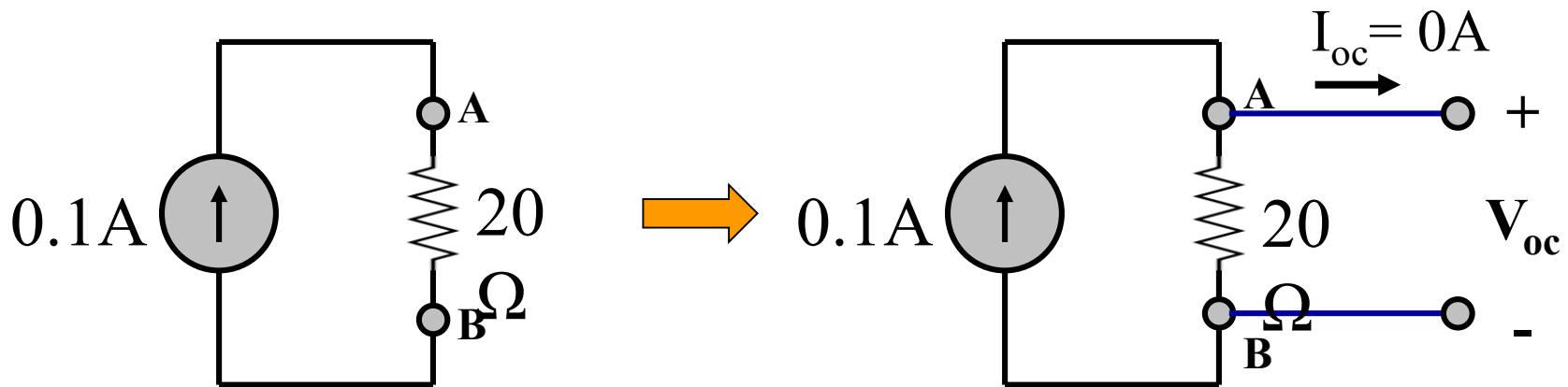


Short circuiting the resistor

- 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



Open circuiting the resistor

- In Fig 7b, 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)

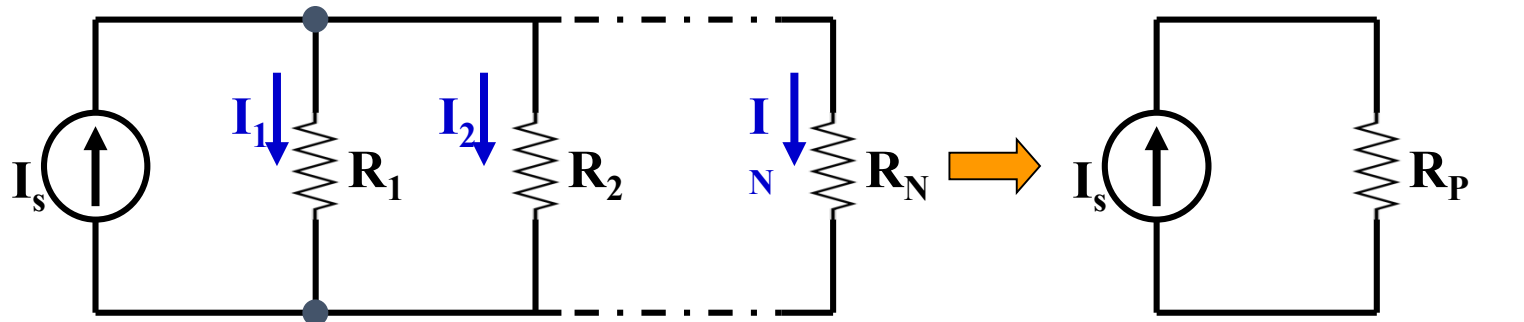
Prefixes: Memorize and **apply** them!

|       |       |            |
|-------|-------|------------|
| 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



Equivalent Resistance  $R_p$ :

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

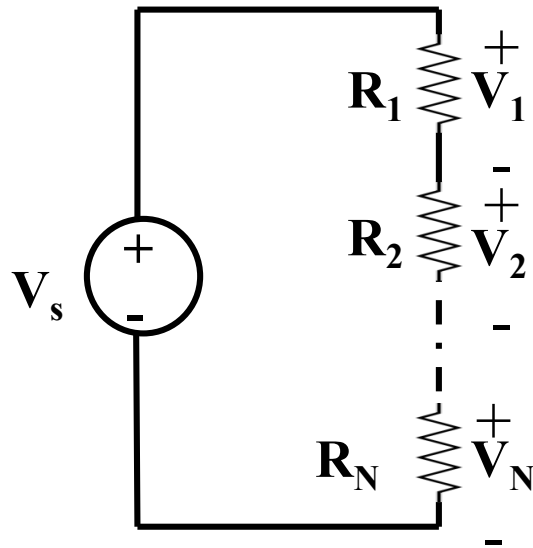
## Current Divider Rule

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

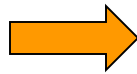
- Current ( $I_s$ ) from the source will have to be shared between the resistors ( $R_k$ ) in each branch

# Series network (Highlights)

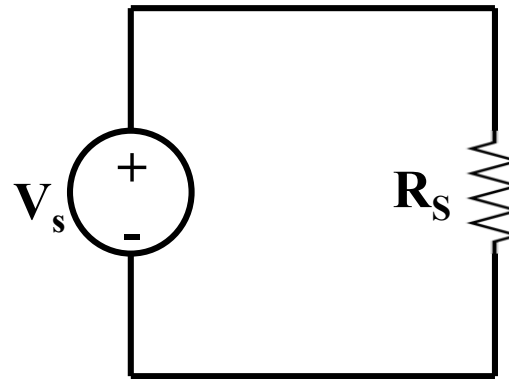
## Series Network



Equivalent Resistance  $R_p$ :



Series resistive network



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

## Voltage Divider Rule

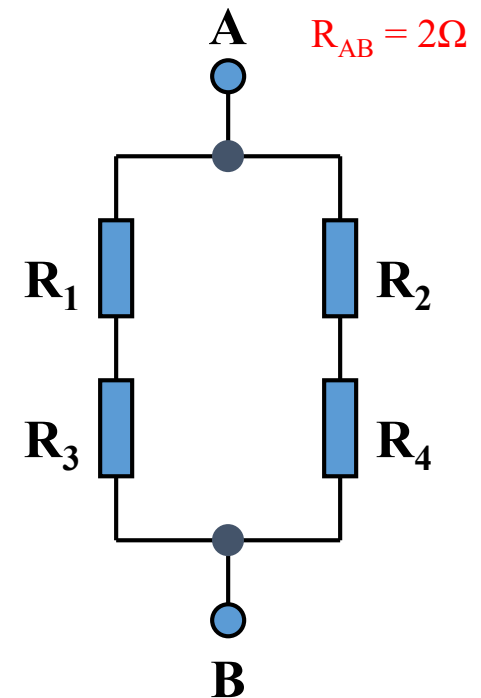
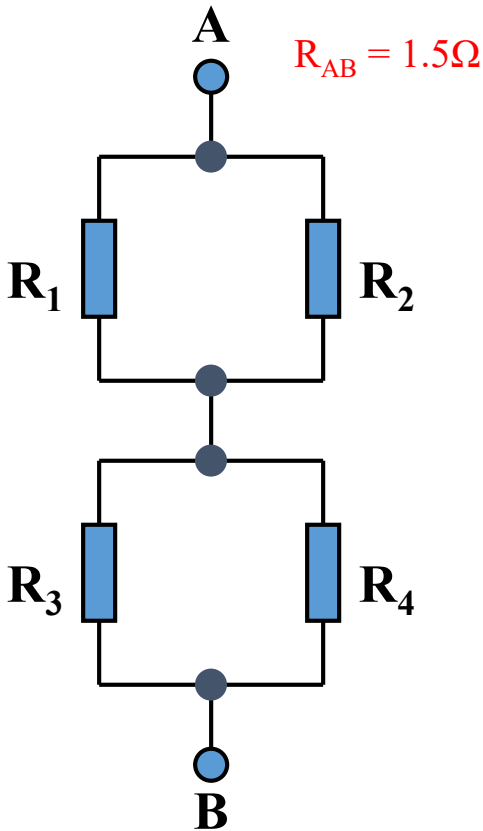
$$V_k = \frac{R_k}{R_S} V_s$$

- 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 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

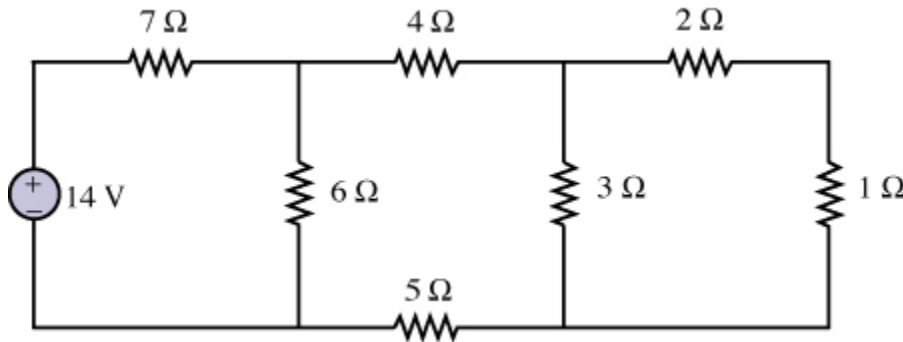
What is the equivalent resistance seen by the source?

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

What is power supplied by the source?

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

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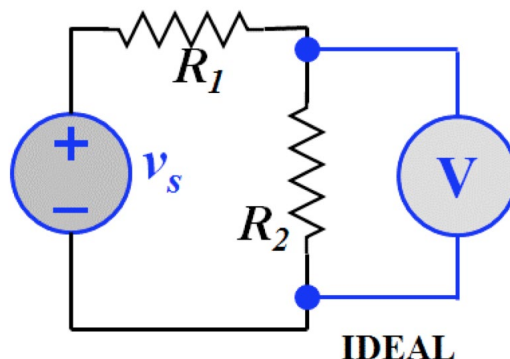


# IV. Measuring Instruments - Voltmeter

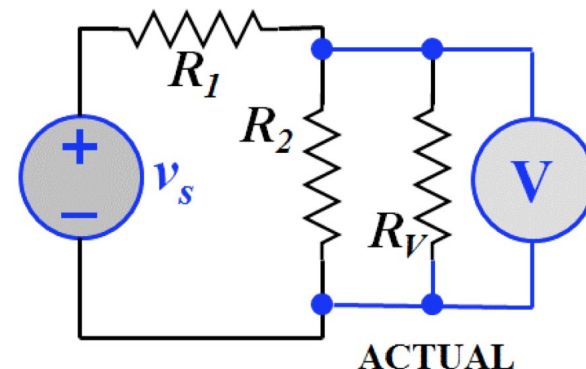
- Voltmeter measures voltage across a circuit element



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



Placement of an ideal voltmeter to measure the PD across  $R_2$



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

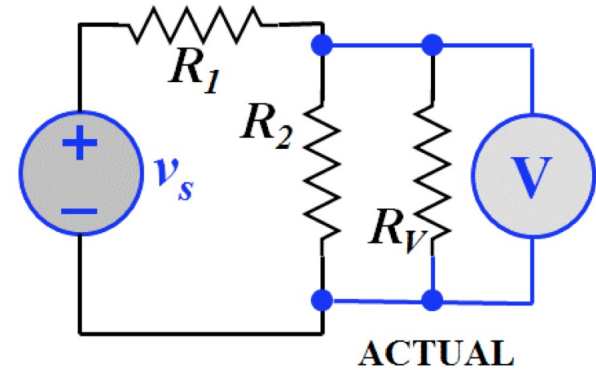
In middle figure, voltmeter has no effect on original circuit. In right figure, voltmeter will steal current from  $R_2$ . This will change the voltage measured across  $R_2$ . Thus, the PD measured with a voltmeter is lower than the true value.

# 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)  $R_1 = R_2 = 1M\Omega$        $V = 1.67V$



# Ammeter

- Ammeter measures current

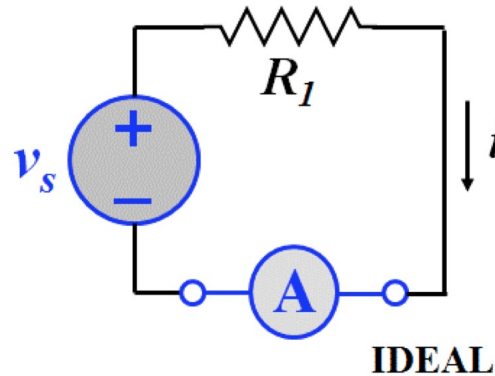
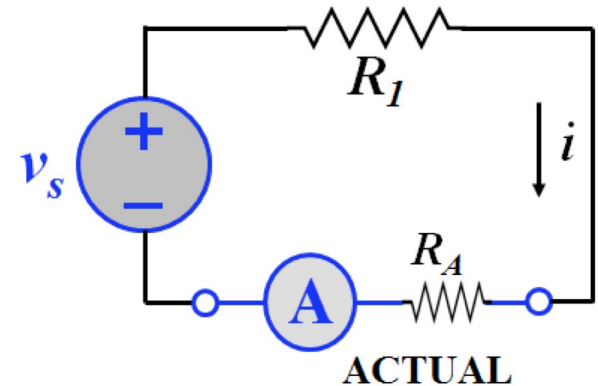


Image of typical current with a measuring range up to 20A

Placement of an ideal ammeter to measure current through  $R_1$



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

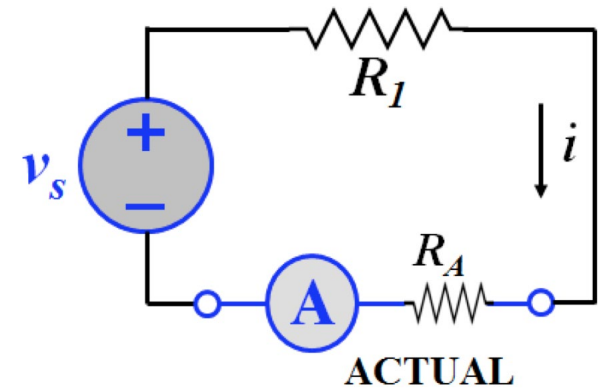
In middle figure, ammeter has no effect on original circuit.  
In right figure, ammeter contains some resistance ( $R_A$ ), adding to the total resistance, lowering the measured current. **Thus, the current measured with an ammeter is lower than the true value.**

# 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)  $R_1 = 2\Omega$       $I = 1.33A$



# Revision on DC (Part II)

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V. Nodal Voltage Analysis, Mesh Current Analysis, Superposition  
(Ch. 3, 4.3)

VI. Thevenin Equivalent Circuit, Norton Equivalent Circuit,  
Source Transformation  
(Ch. 4.4 - 4.6)

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

# V. Nodal Voltage Analysis (NVA)

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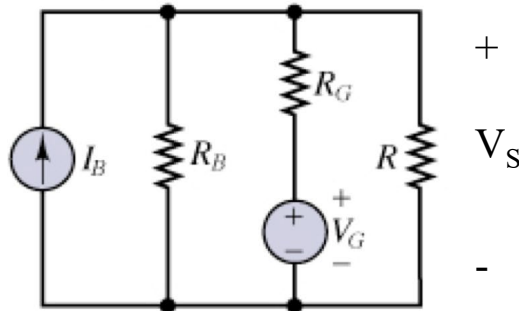
## KCL & Ohm's law in action

- The method of nodal voltage analysis is an application of KCL and Ohm's law together
- The unknown variables that you will solve for are **node voltages**
- We will apply KCL at a node and express the unknown currents as unknown node voltages

# Example on how to do NVA

**Find the voltage across the current source,  $V_S$ :**

Given:  $I_B = 12\text{A}$ ,  $V_G = 12\text{V}$ ,  $R_G = 0.3\Omega$ ,  $R_B = 1\Omega$ ,  $R = 0.23\Omega$



**Apply KCL at  $V_S$ :**

$$I_B = \frac{V_S}{R_B} + \frac{V_S - V_G}{R_G} + \frac{V_S}{R}$$

$$12 = \frac{V_S}{1} + \frac{V_S - 12}{0.3} + \frac{V_S}{0.23}$$

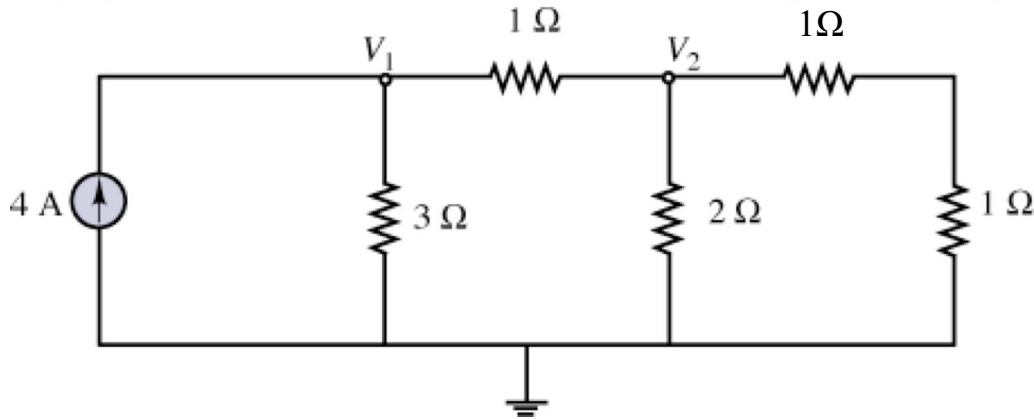
$$V_S = 5.99\text{V}$$

- Note that the negative terminal of  $V_G$  is used as a reference (0V) in the example
- The value of  $V_S$  is also referenced to this node
- The value of the reference node is not important since we are only interested in the voltage difference

# Worked Example on NVA 1

Use nodal voltage analysis to find  $V_1$  and  $V_2$ . (Answer:  $V_1 = 4.8\text{V}$ ,  $V_2 = 2.4\text{V}$ )

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**First method:**

- Apply KCL at  $V_1$  (1)
- Apply KCL at  $V_2$  (2)
- Solve equations (1) and (2)

**Alternate method:**

- Combine all the resistors to find  $V_1$  first
- Then combine the 3 resistors on the right followed by voltage divider rule to find  $V_2$

# Mesh Current Analysis (MCA)

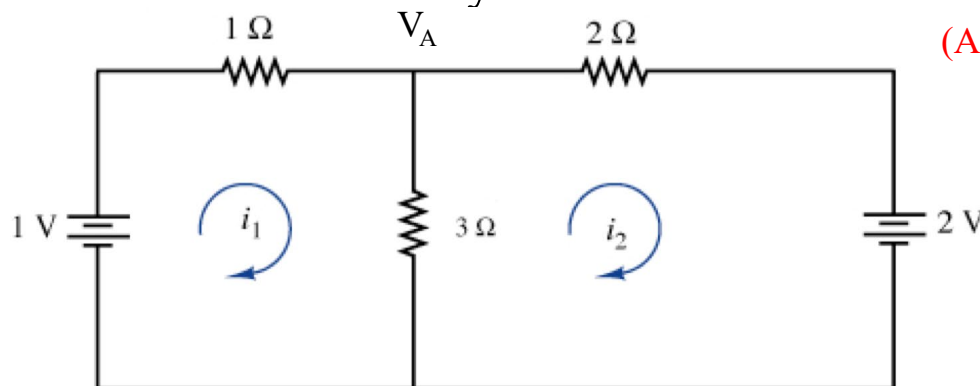
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## KVL & Ohm's law in action

- The method of mesh current analysis is an application of KVL and Ohm's law together
- The unknown variables that you will solve for are **mesh currents**
- From KVL, the sum of voltage drops and rise must equal zero
- The voltage differences are expressed as the current going through each branch in the mesh

# Example on how to do MCA

Use mesh current analysis to find the current through the  $3\Omega$  resistor.



(Answer:  $i_{3\Omega} = 4/11\text{A}$ )

-There are 2 meshes and hence 2 mesh currents

-Apply KVL to each of these 2 meshes

**Apply KVL to mesh 1:**

$$1 = i_1(1 + 3) - 3i_2$$

$$4i_1 - 3i_2 = 1 \quad (1)$$

**Useful tip:**

- keep voltages of sources on one side of the equation, and keep voltages of resistors on the other side

**Apply KVL to mesh 2:**

Follow the defined direction of the mesh current

$$-2 = i_2(2 + 3) - 3i_1$$

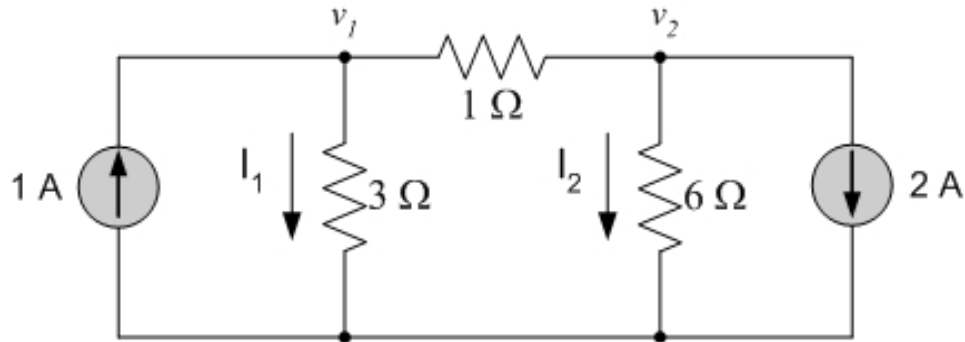
$$5i_2 - 3i_1 = -2 \quad (2)$$

**Now, solve equation (1) and (2):**

$$i_{3\Omega} = i_1 - i_2$$

# Worked Example on MCA 1

Use mesh current analysis to find currents  $I_1$  and  $I_2$ . (Answer:  $I_1 = I_2 = -0.5\text{A}$ )



-You see 3 meshes, but only the middle mesh is unknown, the other 2 are defined by the current sources.

-For simplicity, defined the direction of known mesh currents in the same direction as the sources.

# Quick note on choosing NVA and MCA

---

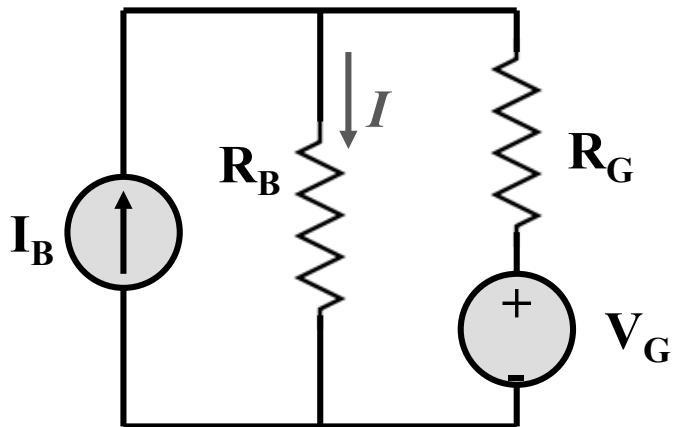
How do you choose between NVA and MCA?

- Your choice should not be due to level of familiarity between the methods.
- One consideration is whichever is simpler to use for a given circuit.
- How then do you decide what is simpler?
- For a start, having fewer equations certainly makes solving easier.

# Superposition

## The method

- This method applies only to circuits that have **multiple sources**
- In such case, it can come in handy (or not)
- In a circuit with multiple sources, superposition considers the current or voltage associated with a given branch for one of the sources, while turning the rest off



Basic circuit with 2 sources

**Aim: Find the current through  $R_B$ .**

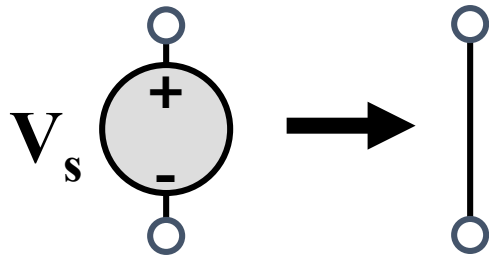
1. Find the current ( $I_1$ ) through  $R_B$  when only  $I_B$  is present ( $V_G$  is removed)
2. Find the current ( $I_2$ ) through  $R_B$  when only  $V_G$  is present ( $I_B$  is removed)
3. The net current  $I = I_1 + I_2$

# How do we “remove” a current source or voltage source?

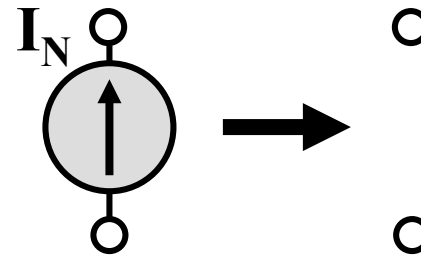
## Disabling sources

**Voltage source:** If the voltage source does not exist, the voltage across the terminals would be zero. It looks like a short circuit. (Left Figure)

**Current source:** If the current source does not exist, the current through it would be zero. It looks like an open circuit. (Right Figure)

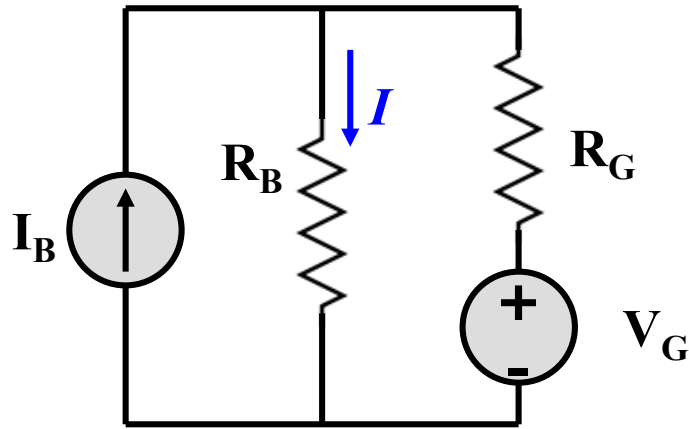


Disable a voltage source by  
Replacing with a short circuit.



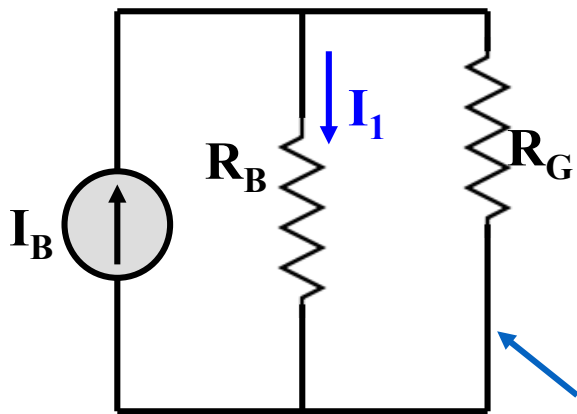
Disable a current source by  
Replacing with an open circuit.

# Apply the tips to Fig (top row)



Basic circuit with 2 sources

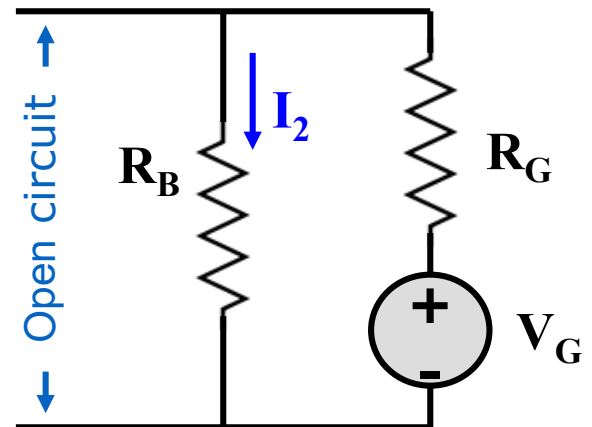
**Disabling  $V_G$ ,  $V_G = 0$**



$$I = I_1 + I_2$$

Short circuit

**Disabling  $I_B$ ,  $I_B = 0$**

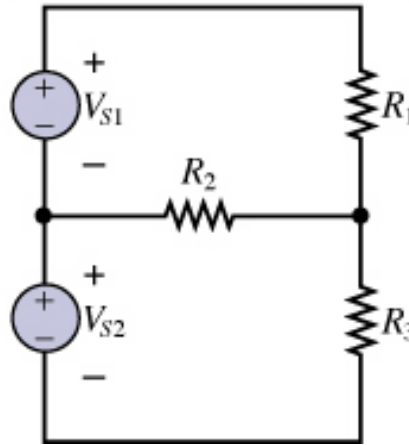


# Worked Example on Superposition

Determine the current through  $R_1$  using superposition.

Given  $R_1 = 560\Omega$ ,  $R_2 = 3.5k\Omega$ ,  $R_3 = 810\Omega$ ,  $V_{S2} = V_{S1} = 90V$

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a. First, short  $V_{S1}$   
Voltage across  $R_1$ :

$$V_{R1a} = \frac{R_1 \parallel R_2}{(R_1 \parallel R_2) + R_3} V_{S2}$$
$$= \left( \frac{560 \parallel 3500}{(560 \parallel 3500) + 810} \right) 90$$
$$= 33.61V$$

Current through  $R_1$ :

$$I_{R1a} = V_{R1a} / R_{1a}$$
$$= 33.61 / 560$$
$$= 0.06A$$

# Worked Example on Superposition

---

b. Next, short  $V_{S2}$

Current through  $R_1$ :

$$I_{R1b} = \frac{V_{S1}}{R_1 + (R_2 \parallel R_3)} = \frac{90}{560 + (3500 \parallel 810)} \\ = 0.074A$$

**Take careful note of the directions defined for each of these currents.**

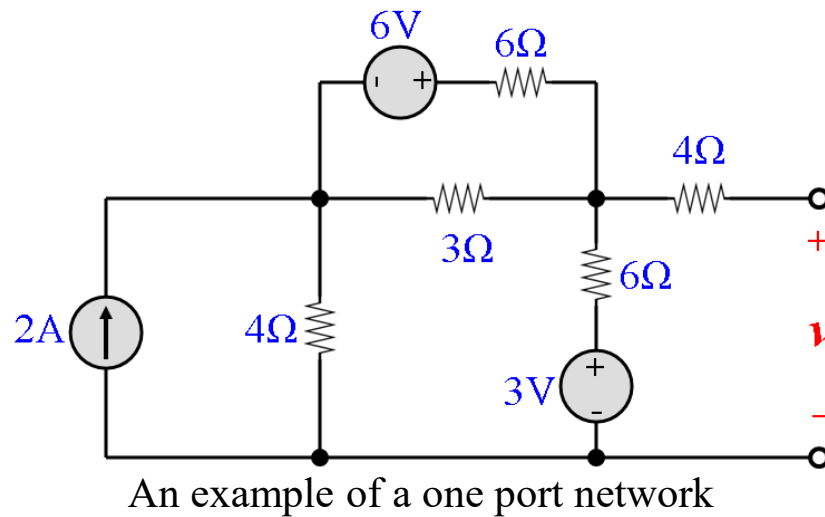
Finally,

$$I_{R1} = I_{R1a} + I_{R1b} = 0.134A$$

# One-Port Network

## Introduction

- A **one port network** is simply a **two terminal device** (See Fig below)

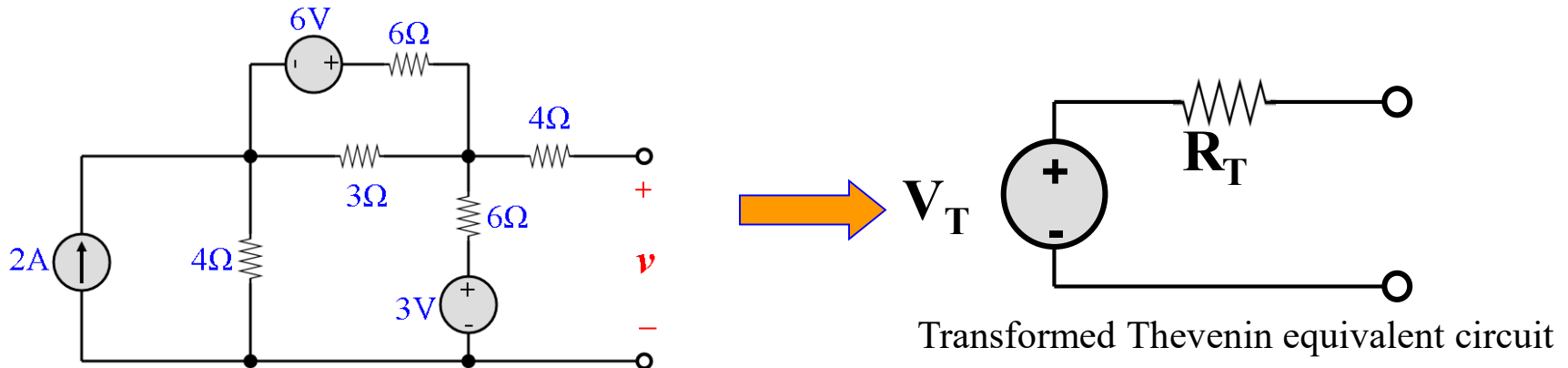


- Given a number of different resistor loads, if you were asked to find the current and voltage at the terminals for each resistor, you would have to recalculate the whole circuit
- A different load will give you different output current & voltage

# One-Port Network

## Simpler analysis

- Transform any 2 terminal circuit into a circuit that is as simple as having 1 resistor and 1 source (see Fig 2)



The first part of this unit is organized into the following 3 sections:

- Thevenin equivalent
- Norton equivalent
- Source transformation

The last part of this unit will cover all concepts in Block A and apply them to dependent sources.

# VI. Thevenin

## Definition

- Any one-port network composed of **ideal** voltage and current sources, and **linear** resistors, can be represented by an equivalent circuit consisting of an ideal **voltage source**  $V_T$  in **series** with an equivalent **resistance**  $R_T$

## Deriving the Thevenin equivalent circuit

**Step 1: Remove the load** from the rest of the one port network. This is the first most fundamental step.

**Step 2: Find the equivalent resistance  $R_T$ .** Disable all ideal sources then find the resistance across the terminals.

For voltage source – replace with short circuit

For current source – replace with open circuit

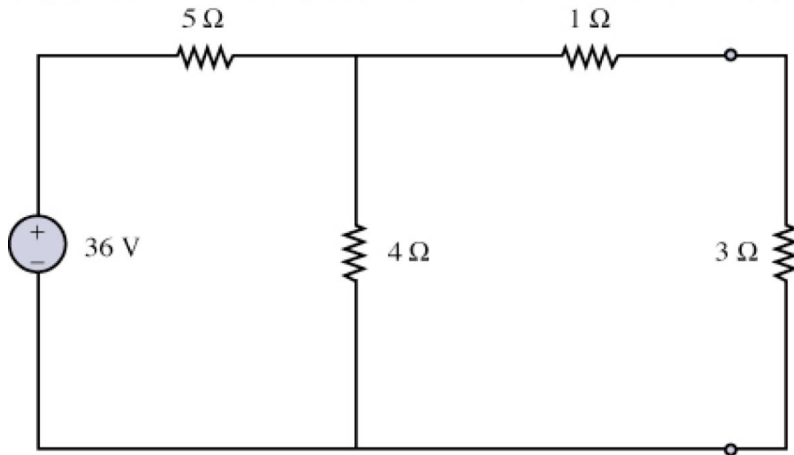
**Step 3: Find the Thevenin voltage source.** The Thevenin voltage source is equal to the open circuit voltage seen across the terminals (with no load). Solve for this voltage using any preferred method (NVA, MCA, superposition).

# Worked Example on Thevenin 1

Derive the Thevenin equivalent circuit seen by the  $3\Omega$  load.

Answer:  $R_{th} = 3.22\ \Omega$ ,  $V_{th} = 16\ V$

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Steps:

1. Remove the  $3\Omega$  load
2. Find  $R_T$  (disable the voltage source)
3. Find  $V_T$  (with no load)
4. Draw the Thevenin circuit

# Norton

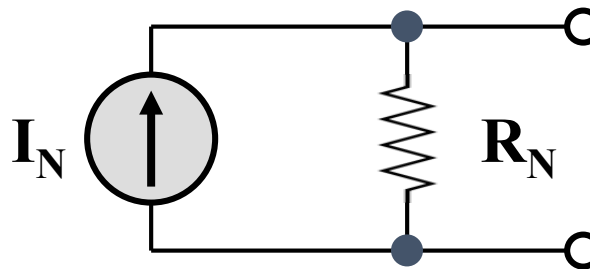
## Definition

- Any one-port network composed of **ideal** voltage and current sources, and **linear** resistors, can be represented by an equivalent circuit consisting of an ideal **current source**  $I_N$  in **parallel** with an equivalent **resistance**  $R_N$

## Deriving the Norton equivalent circuit

**Steps 1 and 2** for deriving the Norton equivalent circuit are exactly the same as that for Thevenin.

**Step 3: Find the Norton current source.** The Norton current source is equal to the short circuit current seen across the terminals (with no load). Solve for this voltage using any preferred method (NVA, MCA, superposition).

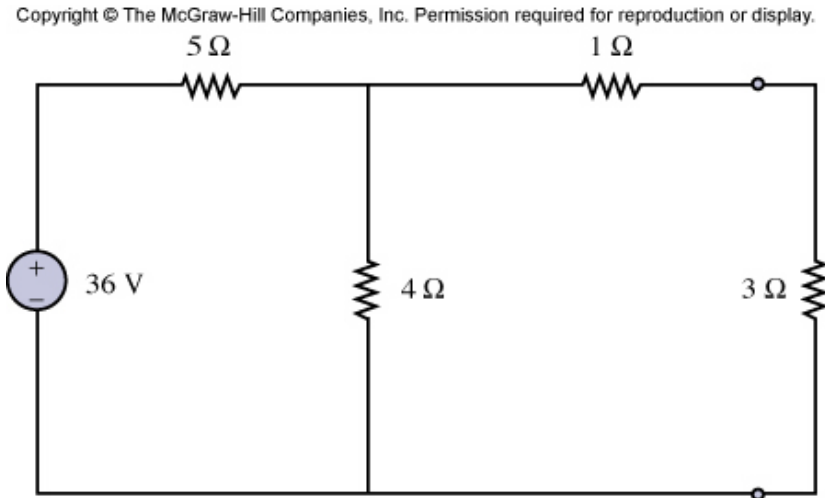


Transformed Norton equivalent circuit

# Worked Example on Norton 1

Derive the Norton equivalent circuit seen by the  $3\Omega$  load.

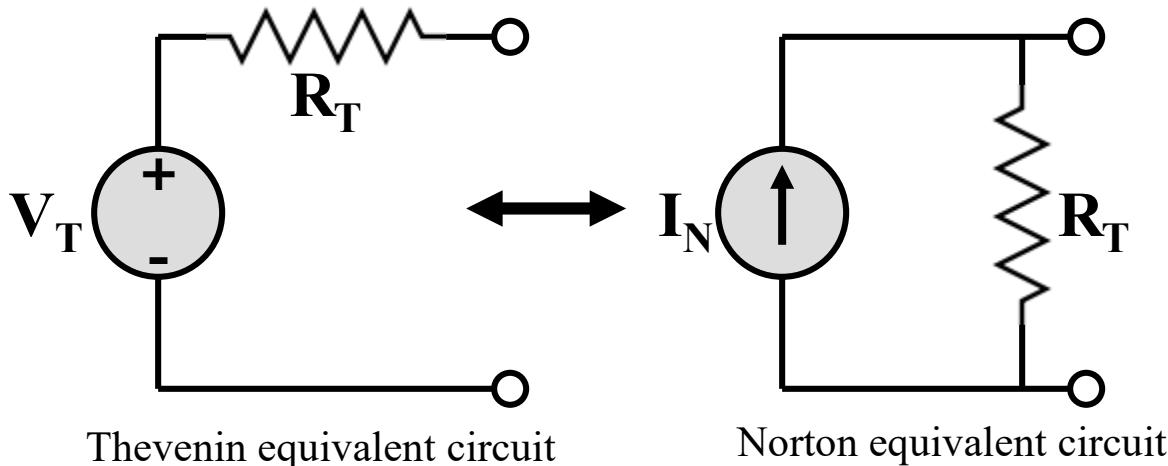
Answer:  $R_N = 3.22\ \Omega$ ,  $I_N = 4.96\ \text{A}$



# Source Transformation

## Definition

- This trick rests on the fact that the Thevenin and Norton forms are equivalent to each other and therefore are also interchangeable



**We can transform between the two equivalent circuits, observing each time that:**

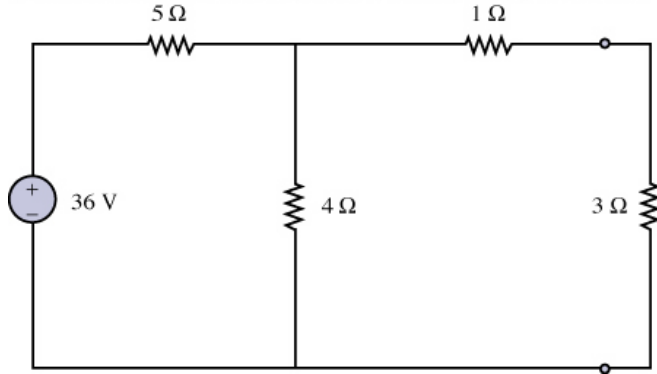
$$V_T = I_N R_T$$

- Rather than transform the whole circuit in one go to Thevenin or Norton equivalent forms, we can instead transform part of the circuit
- The process of merge transform and merge again can be repeated

# Worked Example on Source Transformation 1

Derive either of the equivalent circuit forms seen by the  $3\Omega$  load.

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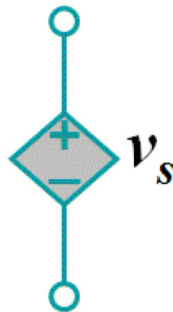


# Dependent Sources

- All the sources we have come across are independent source
  - > For a voltage source, the voltage maintained across the source is fixed
  - > For a current source, the current through the source is fixed
- There also exist dependent sources in circuit theory
- Unlike independent sources, the value of a dependent source is not predetermined, but is set by the current or voltage through a specific branch

## Symbol

- The symbol for an independent source is a circle
- For a dependent source, the symbol is a diamond



Dependent voltage source

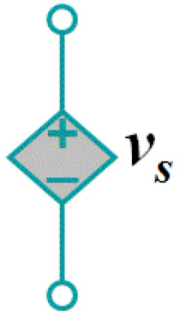


Dependent current source

# Dependent Sources

## Dependent Voltage Source

$v_S$  is the voltage source across the terminals.



### **Current Controlled Voltage Source**

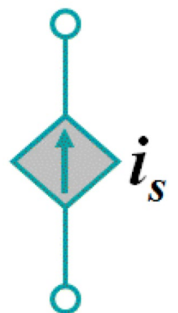
For example,  $v_S = 5i_X$ . The current  $i_X$  is not the current through the source but belongs to another branch.

### **Voltage Controlled Voltage Source**

For example,  $v_S = 7v_X$ . The voltage  $v_X$  is not the source voltage. As  $v_X$  changes, so also  $v_S$  according to the above relations.

## Dependent Current Source

$i_S$  is the current source through the terminals.



### **Current Controlled Current Source**

For example,  $i_S = 5i_X$ . The current  $i_X$  is not the current through the source but belongs to another branch.

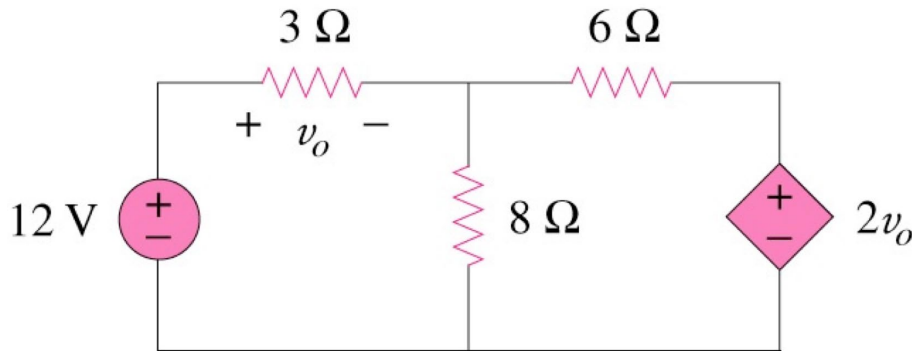
### **Voltage Controlled Current Source**

For example,  $i_S = 7v_X$ . The voltage  $v_X$  is not the source voltage. As  $v_X$  changes, so also  $i_S$  according to the above relations.

# Worked Example on Dependent Source 1

Calculate  $v_o$  in the circuit.

Answer:  $v_o = 3.65 \text{ V}$



Hints:

1. The dependent source here is a voltage controlled voltage source
2. Apply KCL

# Summary on DC Revision

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- The sections covered are the fundamental concepts to learn Blocks A, B, and C.
  - I. Kirchhoff's Current, Voltage Law, and Ohm's Law
  - II. Sources, Short Circuit, Open Circuit
  - III. Resistive Networks
  - IV. Measuring Instruments
  - V. Nodal Voltage Analysis, Mesh Current Analysis, Superposition
  - VI. Thevenin Equivalent Circuit, Norton Equivalent Circuit, Source Transformation
- Students can refer to the textbook for more working examples

Alexander & Sadiku, "Fundamentals of Electric Circuits" , 7<sup>th</sup> Edition, McGraw Hill