Circuit Analysis and Design

Academic year 2025/2026 – Lecture 3

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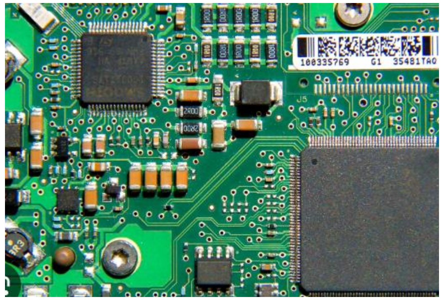
"A good student never steal or cheat"

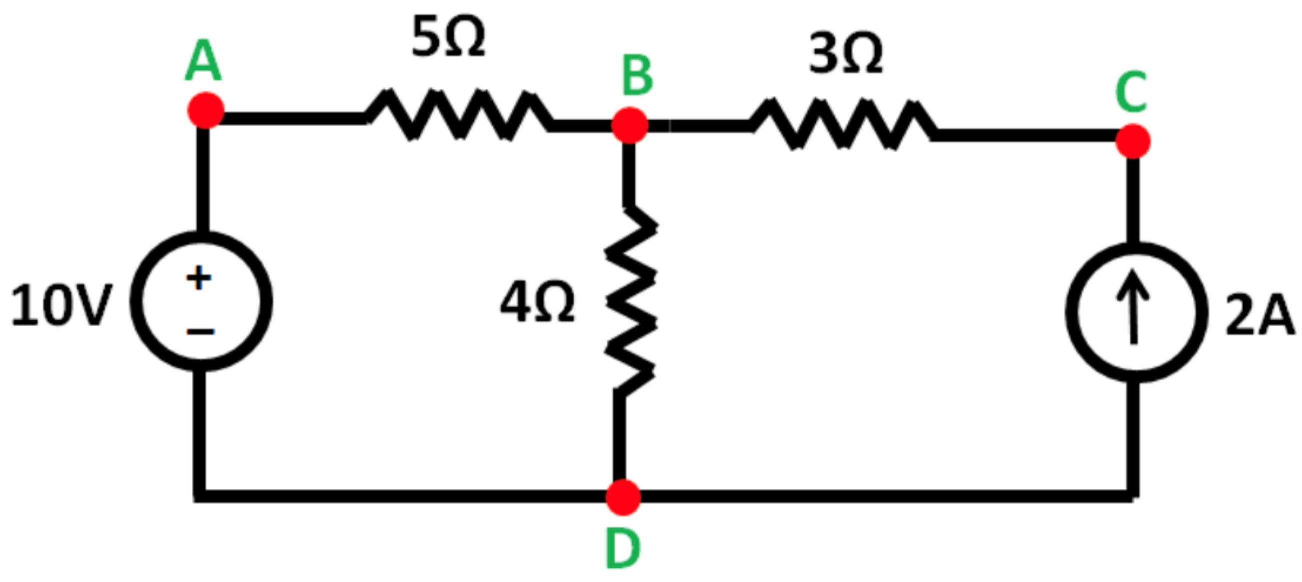


Agenda

- ❑ Definition of node, branch, path, loop, and mesh
- ❑ Resistor
- ❑ Ohm's law
- ❑ Kirchhoff's current law (KCL)
- ❑ Kirchhoff's voltage law (KVL)
- ❑ Equivalent resistance of series connection of resistors
- ❑ Equivalent resistance of parallel connection of resistors
- ❑ Summary

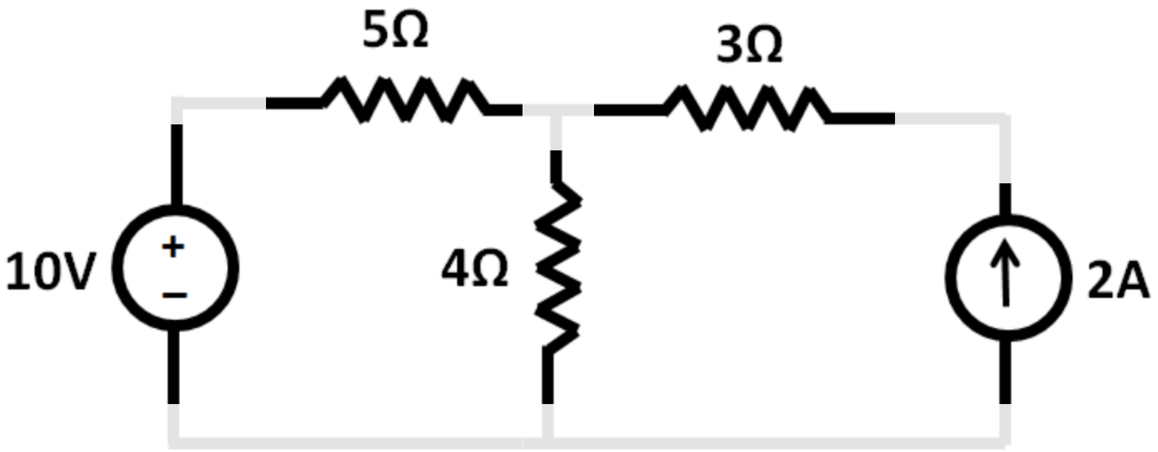
Circuit

- A circuit is an interconnection of elements, which can be voltage sources, current sources, resistors, capacitors, inductors, coupled coils, transformers, op amps, etc.



What is Branch

- **A branch represents the single circuit element like resistor, capacitor, inductor, voltage, or current source**



- For example, for the circuit shown in figure 1, there are five branches. A 10 V voltage source, 2A current source, 4 **Ω**, 5 **Ω,** and 3 **Ω** resistors.
- Current in a branch as always same.

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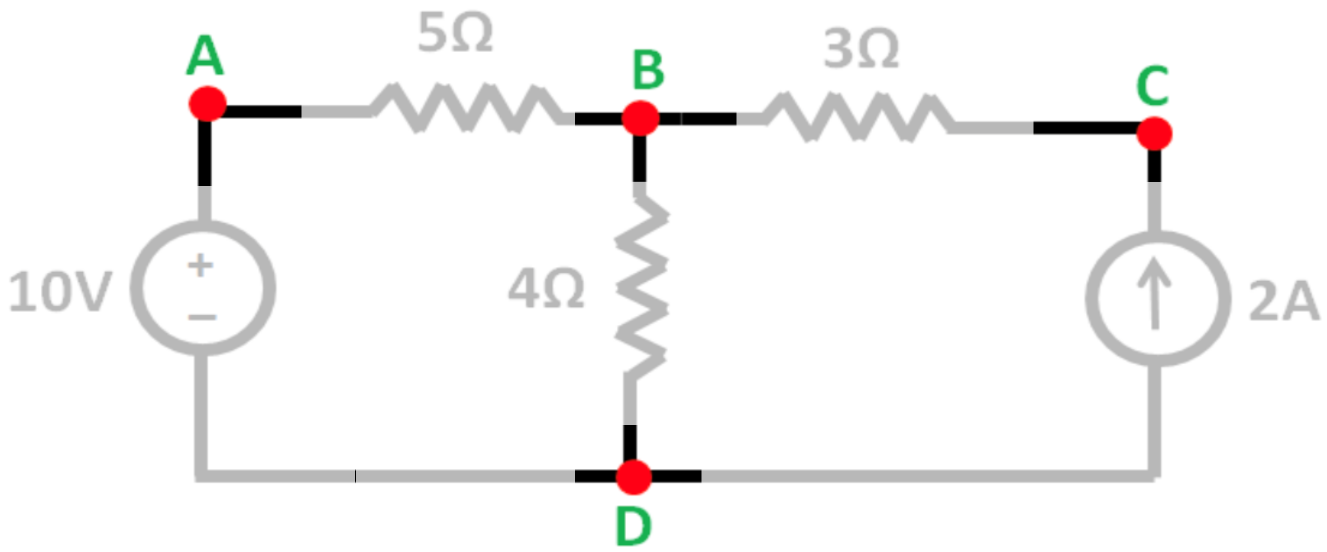
What is Node?

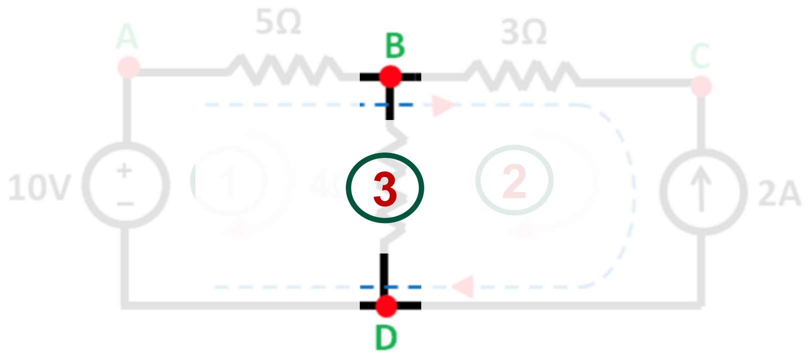
- A node is a point in the circuit where two or more circuit elements (or branch) are connected)



- For example, the above circuit contains Four Nodes. The node A, B, C, and D

What is Loop

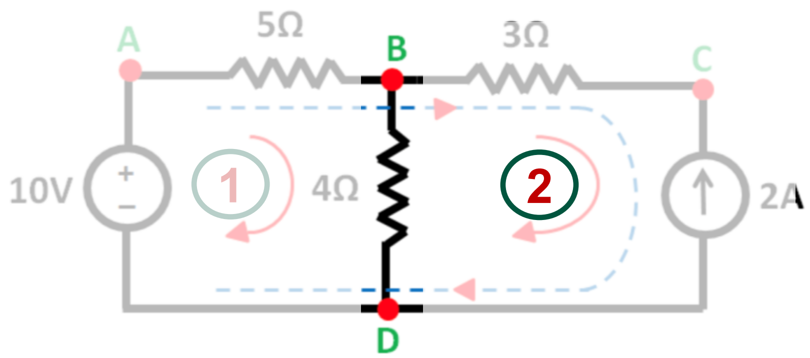
- ❑ Any closed path in circuit is called a loop
  - A closed path formed by starting at a node, passing through a set of nodes, and returning to starting node without passing through any node more than once.



- ❑ For example, the circuit contains three loops,
  - – 1st loop A-B-D-A, 2nd loop B-C-D-B, 3rd loop is A-B-C-D-A

What is Mesh

- A mesh is a closed path in the circuit, which does not contain any other close path inside it.
- 1st loop A-B-D-A, 2nd loop B-C-D-B does not contain any loop inside, Therefore there are two meshes in this circuit



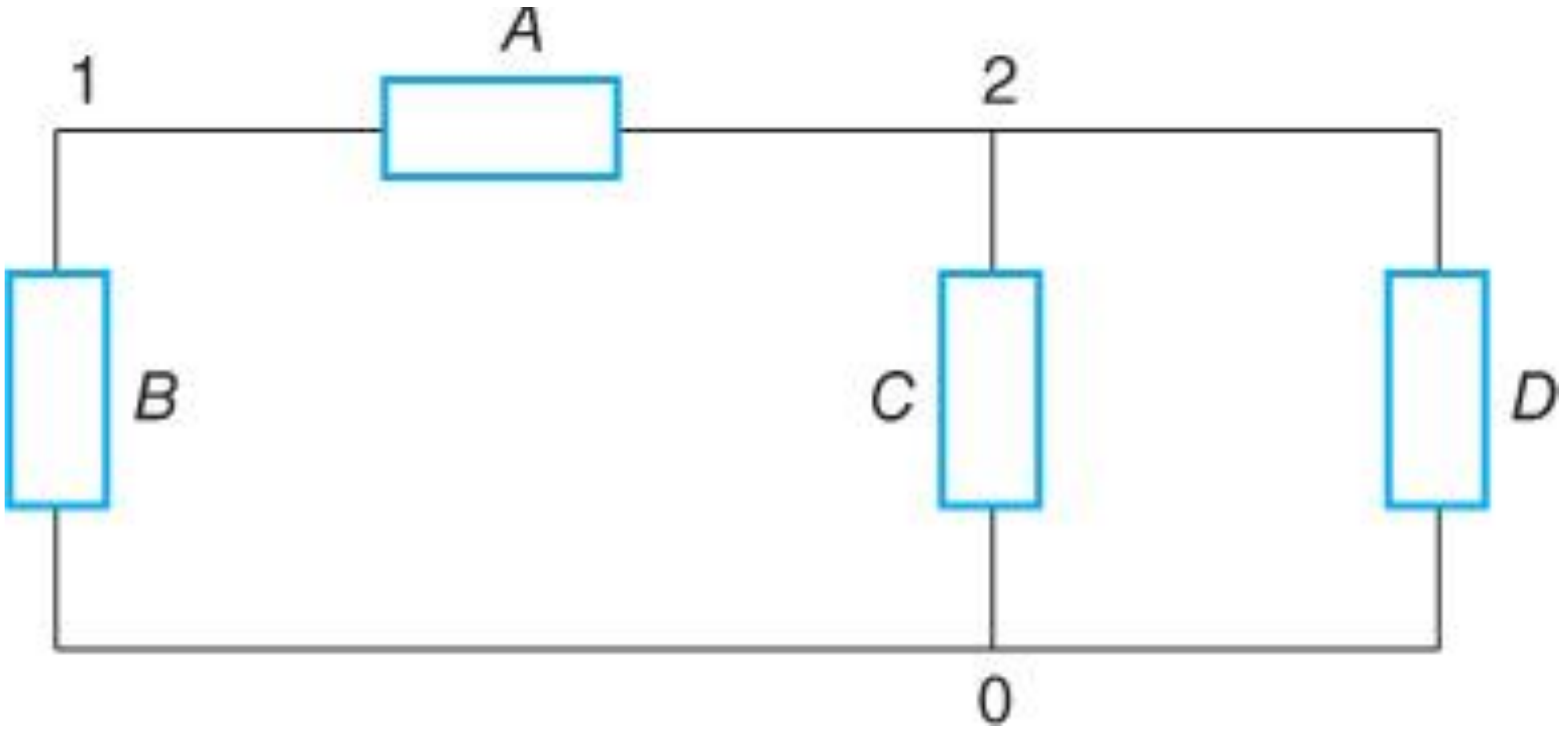
- All meshes are loops but not oops are meshes

Further Definitions, Node, Loop, and Mesh

- A **simple node** is a node that connects two elements.
- An **essential node** is a node that connects three or more elements.
- A **path** in a circuit is a series of connected elements from a node to another node that does not go to the same node more than once.
- The **ground node** where the voltage is at ground level is usually taken to be the reference node.
- The voltage of a node measured with respect to a reference node is called **node voltage**.
- The current through a mesh is called **mesh current**.

EXAMPLE 2.1

- Find all the nodes, loops, and meshes for the following circuit.



EXAMPLE 2.1

- Find all the nodes, loops, and meshes for the circuit shown in Figure 2.1.

There are three nodes (labeled as 0, 1, 2).

Node 1 is a simple node

nodes 2 and 0 are essential nodes.

There are three loops in the circuit

0-B-1-A-2-D-0

0-B-1-A-2-C-0

0-C-2-D-0

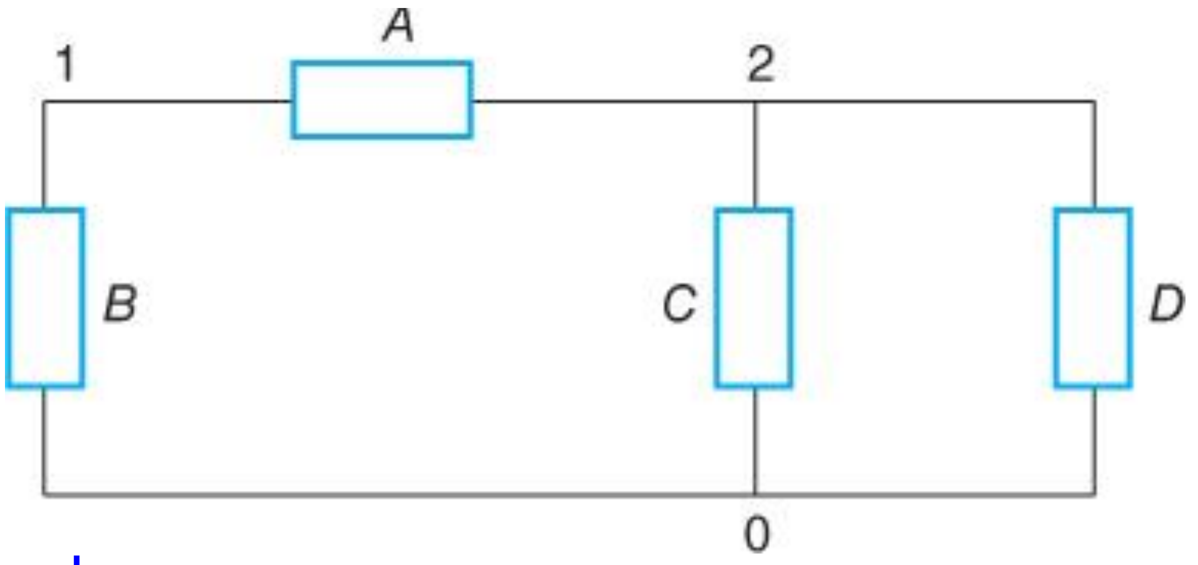
There are two meshes in the circuit

0-B-1-A-2-C-0

0-C-2-D-0

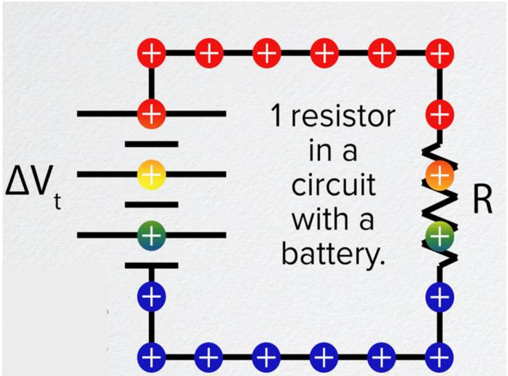
The loop 0-B-1-A-2-D-0 contains two meshes

0-B-1-A-2-C-0 and 0-C-2-D-0.

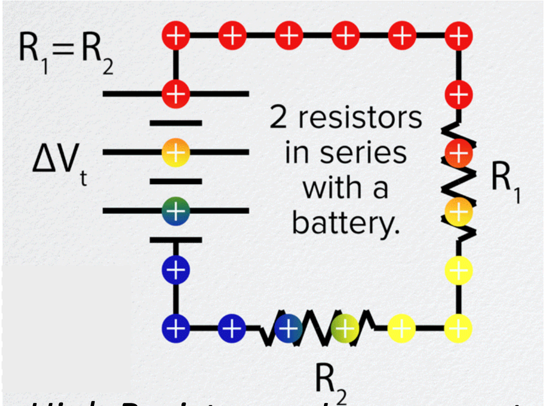


Resistors

- Resistor is a circuit component that regulates flow of current.
- Resistance of resistor is measures of its ability to limit current.
  - When resistance value is large, the amount of current flow through the resistor is small.
  - If resistance value is small, the amount of current flow through the resistor is large

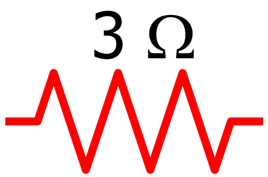


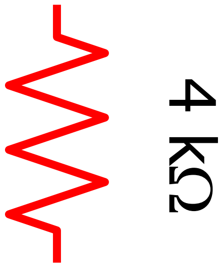
Low Resistance, high current



High Resistance, Low current

- Resistance value of a resistor is determined by conductivity (or resistivity) of material used to make it, as well as its dimensions.
- **Low-power** resistors can be made from carbon composition material made of **fine granulated graphite mixed with** clay. For **high power**, **wire-wound resistors** can be used. The wire-wound resistors are constructed by twisting a wire made of **nichrome** or similar material around a ceramic core.





Circuit Symbol of Resistor


Low Resistance Resistor


High Resistance Resistor

Resistance

- The current density is defined as the amount of current through the unit area. If A is the cross-sectional area of a wire that carries a constant current I, the current density is given by: $J = \frac{I}{A}$
- It can be shown that the current density is proportional to the electric field intensity: $J = \sigma E$, σ is the conductivity of the material.
- Let ℓ be the length of the wire and V be the potential difference (voltage) between the ends of the wire. The potential difference generates a constant electric field E inside the conductor. The potential difference V is related to the electric field through $V = E\ell$
- Substituting $E = V/\ell$ and $J = I/A$ into $J = \sigma E$, we obtain $I/A = \sigma V/\ell$. Thus, $V = [\ell/(\sigma A)]I$.
- The resistance is defined as $$R = \frac{\ell}{\sigma A}$$

Resistance (Continued)

- The resistance is proportional to the length of the wire and inversely proportional to the cross-sectional area of the wire and conductivity of the material.
- The resistivity ρ of the material is the inverse of the conductivity:

$$\rho = 1/\sigma$$

- In terms of the resistivity, the resistance is given by: $R = \dfrac{\rho \ell}{A}$

- The resistance is proportional to the length of the wire and resistivity, and inversely proportional to the cross-sectional area of the wire.
- In terms of resistance R, Equation, $V = \dfrac{\ell}{\sigma A} I = RI$ (Ohms Law) The unit for resistance is ohm (Ω).

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Resistance (Continued)

Example: What is the resistance of a wire with radius 1 mm, length 10 m, conductivity 5×10^4 S/m?.

(A) R=63.662 Ω

(B) R=636.62 Ω

(C) R=6.3662 Ω

(D) R=63 kΩ

Solution:

$$R = \frac{\ell}{\sigma A}$$

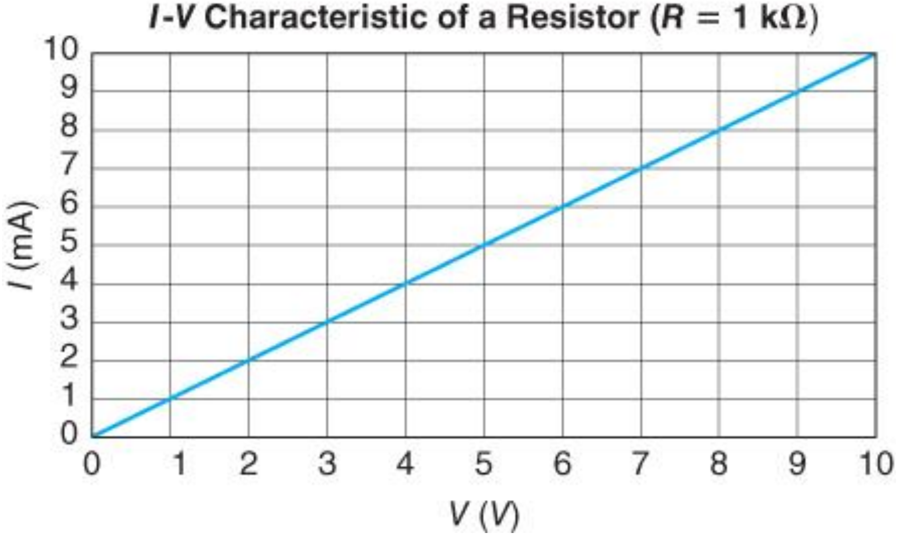
$$= \frac{10}{\pi \times 0.001^2 \times 5 \times 10^4} = 63.662\ \Omega$$

Ohm’s Law (V = RI, I = V/R, R = V/I)

- The voltage-current relation of a resistor is given by: $V = RI$
- The **voltage across a resistor is proportional to the current through the resistor**. The proportionality constant in this linear relation is the resistance *R*. For the given current *I*, the voltage across the resistor increases as *R* increases.
- The current through the resistor is proportional to the voltage across the resistor.
- Conductance defined by G = 1/R. For the given voltage V, the current through the resistor decreases as R increases.
- The unit for conductance is siemens (S). .

FIGURE 2.5

I-V characteristic of a resistor.



Ohm's Law and Power absorbed by Resistor

- The resistance R of a resistor is given by $R = \frac{V}{I}$
- The resistance of a resistor is the ratio of voltage to current.
- Power absorbed by a resistor is given by $P = IV = VI\ (Watt)$
- The power absorbed by a resistor is the product of the current through the resistor and the voltage across the resistor. Substituting V = IR into P = IV, we get

$$P = I^2R\ (Watt)$$

- The power absorbed by a resistor is the product of the square of the current through the resistor and the resistance value. Substituting $I = \frac{V}{R}$ into P = IV, we get $P = \frac{V^2}{R}\ (\text{Watt})$

- Using different units for current, voltage, and resistance in power calculations will lead to power being expressed in different units.

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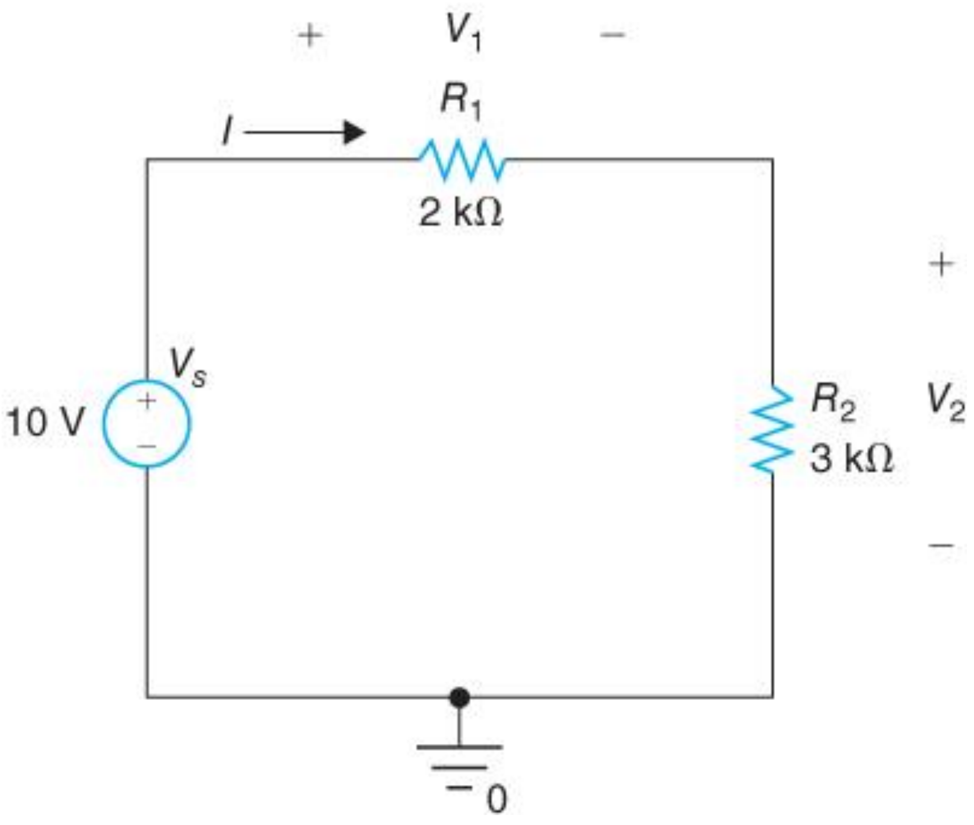
Ohm's Law and Power absorbed by Resistor

- Example: Given I = 2 mA, find V_1, V_2, and powers.

Circuit with two resistors and a voltage source.



- $V_1 = R_1 \times I = 2000 \times 0.002 = 4$ V (Ohm's law)
- $V_2 = R_2 \times I = 3000 \times 0.002 = 6$ V (Ohm's law)
- $P_{R1} = I \times V_1 = 0.002 \times 4 = 0.008$ W = 8 mW
- $P_{R2} = I \times V_2 = 0.002 \times 6 = 0.012$ W = 12 mW
- $P_{Vs} = -I \times V_s = -0.002 \times 10 = -0.02$ W = -20 mW
- Power absorbed by R_1 and R_2 = 20 mW
- Power generated by V_s = -20 mW
- Power absorbed = Power released

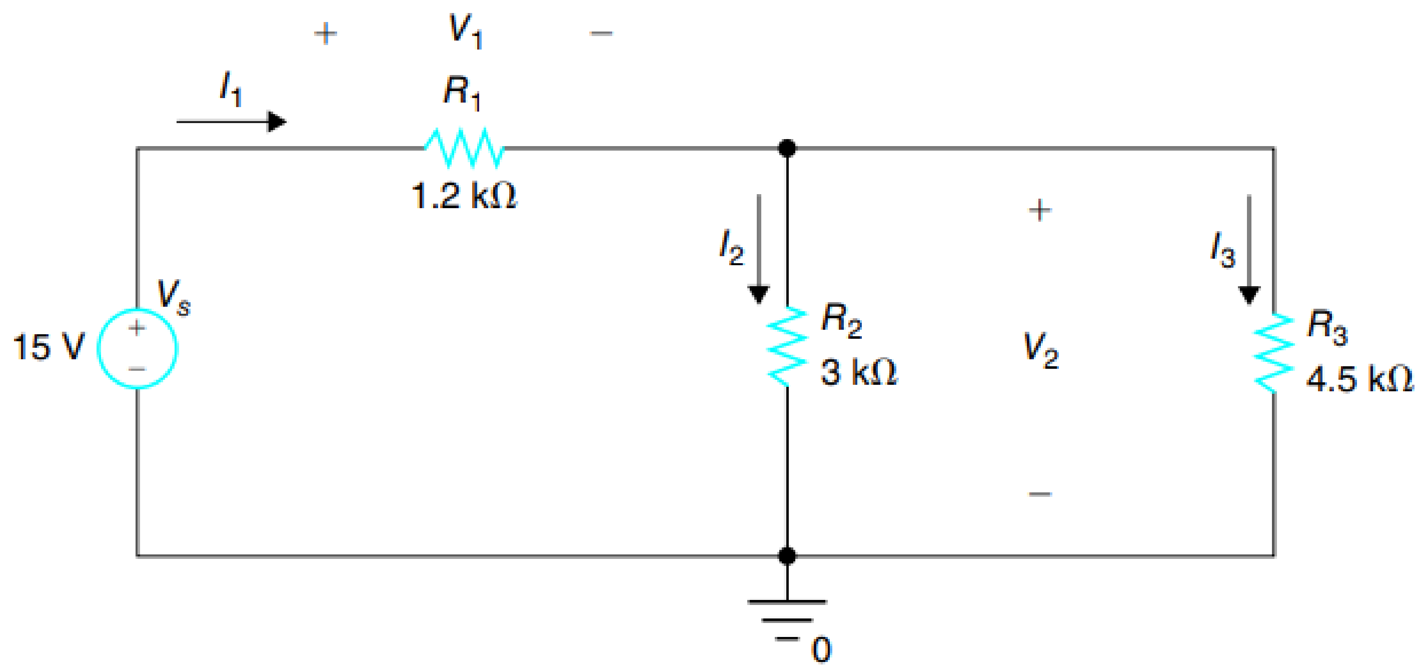
Ohm's Law and Power absorbed by Resistor

Example: Given V_2 = 9 V, find I_2, I_3, V_1, I_1, and powers in the following circuit.

- $I_2 = V_2/R_2$

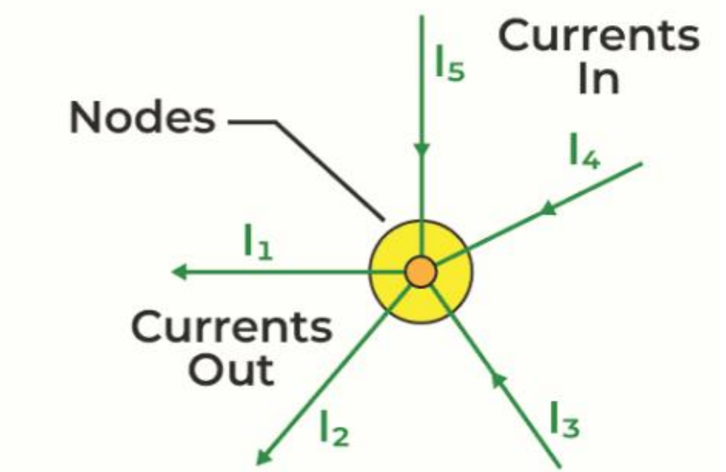
  $I_2 = 9\text{ V}/3\text{ k}\Omega = 3\text{ mA}$
- $I_3 = V_2/R_3$

  $= 9\text{ V}/4.5\text{ k}\Omega = 2\text{ mA}$
- $V_1 = V_s - V_2 = 15\text{ V} - 9\text{ V} = 6\text{ V}$,
- $I_1 = V_1/R_1 = 6\text{ V}/1.2\text{ k}\Omega = 5\text{ mA}$
- $P_{R1} = I_1V_1 = 30\text{ mW}$,
- $P_{R2} = I_2V_2 = 27\text{ mW}$,
- $P_{R3} = I_3V_2 = 18\text{ mW}$,
- $P_{Vs} = -I_1V_s = -75\text{ mW}$
- $P_{R1} + P_{R2} + P_{R3} + P_{Vs} = 0$



Problem P2.1 to P2.14

Kirchhoff's Current Law (KCL)



- The sum of currents entering a node equals the sum of currents leaving the same node.

$$I_3 + I_4 + I_5 = I_1 + I_2$$

  - The number of charges entering a node per second must equal the number of changes leaving the same node per second.

- The sum of currents leaving a node is zero.

$$I_1 + I_2 - I_3 - I_4 - I_5 = 0$$

  - At least one of the currents leaving the node must be negative (meaning that the current actually enters the node).

- The sum of currents entering a node is zero.

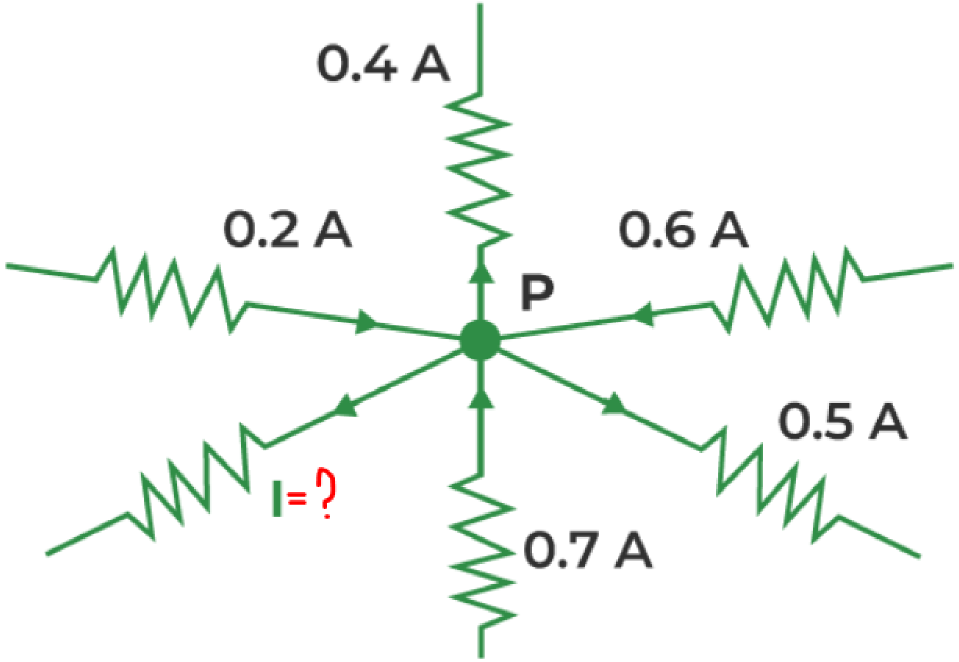
$$-I_1 - I_2 + I_3 + I_4 + I_5 = 0$$

  - At least one of the currents entering the node must be negative (meaning that the current actually leaves the node).

Kirchhoff’s Current Law (KCL)

- The sum of currents entering a node equals the sum of currents leaving the same node.

Example : Find the value of current *I* from the circuit diagram.



- Apply KCL to the **Node P** in the circuit:
- **Current entering = Current leaving**
  - **0.2 A + 0.6 A + 0.7 A = 0.4 A + 0.5 A + I**
  - 0.2 A – 0.4 A + 0.6 A – 0.5 A + 0.7 A – I = 0
  - 1.5 A – 0.9 A – I = 0
  - 0.6 A – I = 0
- **I = 0.6A**

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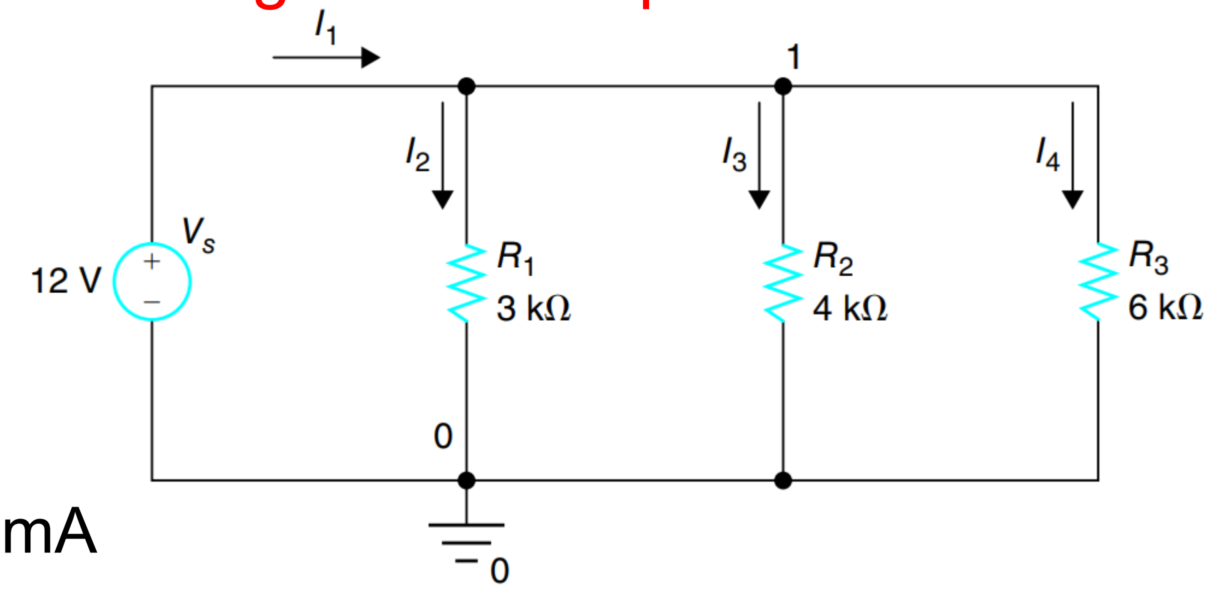
Kirchhoff's Current Law (KCL)

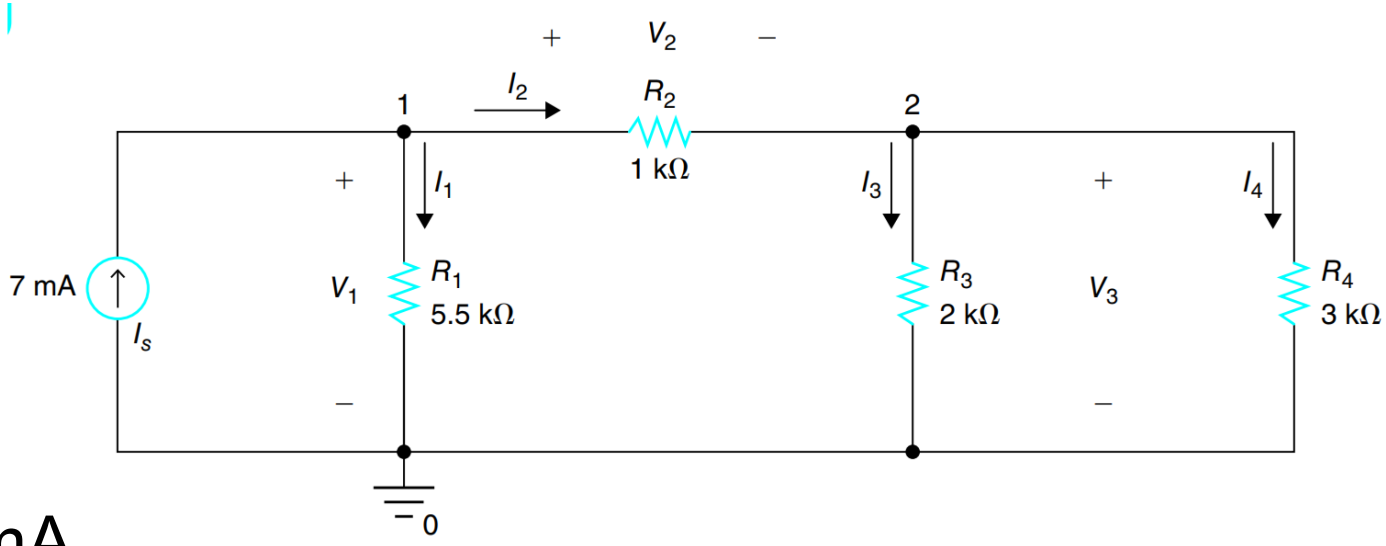
- **Example 2.1**: The sum of currents entering a node equals the sum of currents leaving the same node.



- $I_2 = V_s/R_1$
  $= 12\ \text{V}/3\ \text{k}\Omega = 4\ \text{mA}$
- $I_3 = V_s/R_2 = 12\ \text{V}/4\ \text{k}\Omega = 3\ \text{mA}$
- $I_4 = V_s/R_3 = 12\ \text{V}/6\ \text{k}\Omega = 2\ \text{mA}$
- $I_1 = I_2 + I_3 + I_4 = 4\ \text{mA} + 3\ \text{mA} + 2\ \text{mA} = 9\ \text{mA}$
- Sum of currents entering node1 $= I_1 = 9\ \text{mA}$
- Sum of currents leaving node1 $= I_2 + I_3 + I_4 = 9\ \text{mA}$
- Sum of all currents leaving node1 $= -I_1+I_2+I_3+I_4= -9\text{mA}+4\text{mA}+3\text{mA}+2\ \text{mA} = 0$
- Sum of all currents entering node 1 $= I_1 - I_2 - I_3 - I_4=9\text{mA} - 4\text{mA} - 3\ \text{mA} - 2\text{mA} = 0$

Kirchhoff's Current Law (KCL)

Example 2.3: Given I_3 = 3 mA, find V_3, I_4, I_2, V_2, I_1, and V_1 in the circuit.

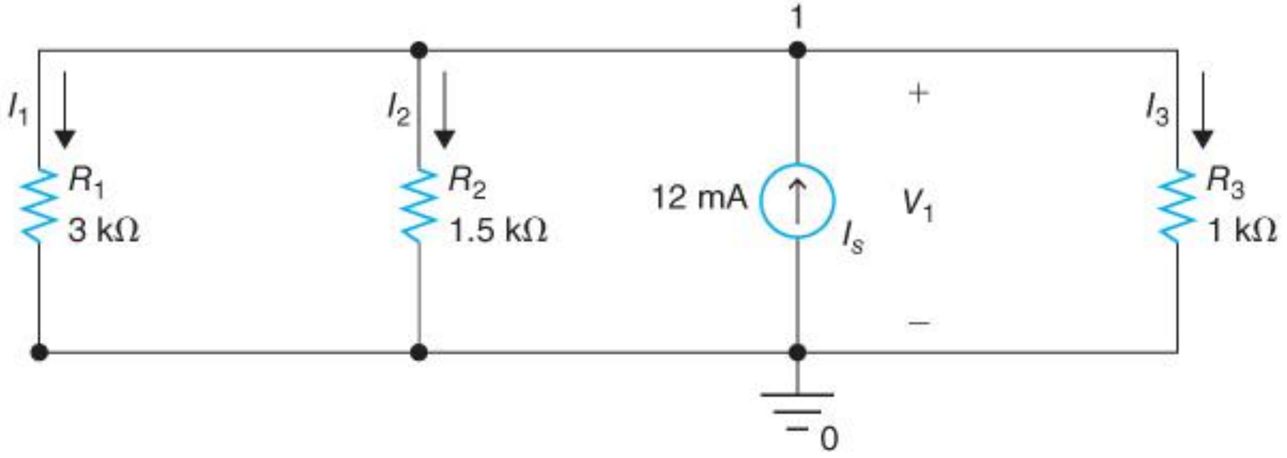


$V = RI$

- $V_3 = R_3 I_3$ = 2000×0.003 = 6 V
- $I_4 = V_3/R_4$ = 6/3000 = 2×10^{-3} A = 2 mA
- $I_2 = I_3 + I_4$ = 3 mA + 2 mA = 5 mA
- $V_2 = R_2 I_2$ = 1000 × 0.005 = 5 V
- $I_1 = I_s - I_2$ = 7 mA – 5 mA = 2 mA
- $V_1 = R_1 I_1$ = 5500 × 0.002 = 11 V

Example 2.4

- Find V_1, in the circuit shown in Figure 2.13. Use KCL?



Options

A. 4 V
B. 6 V
C. 12 V

Multiple Choice

Solution will be provided in class

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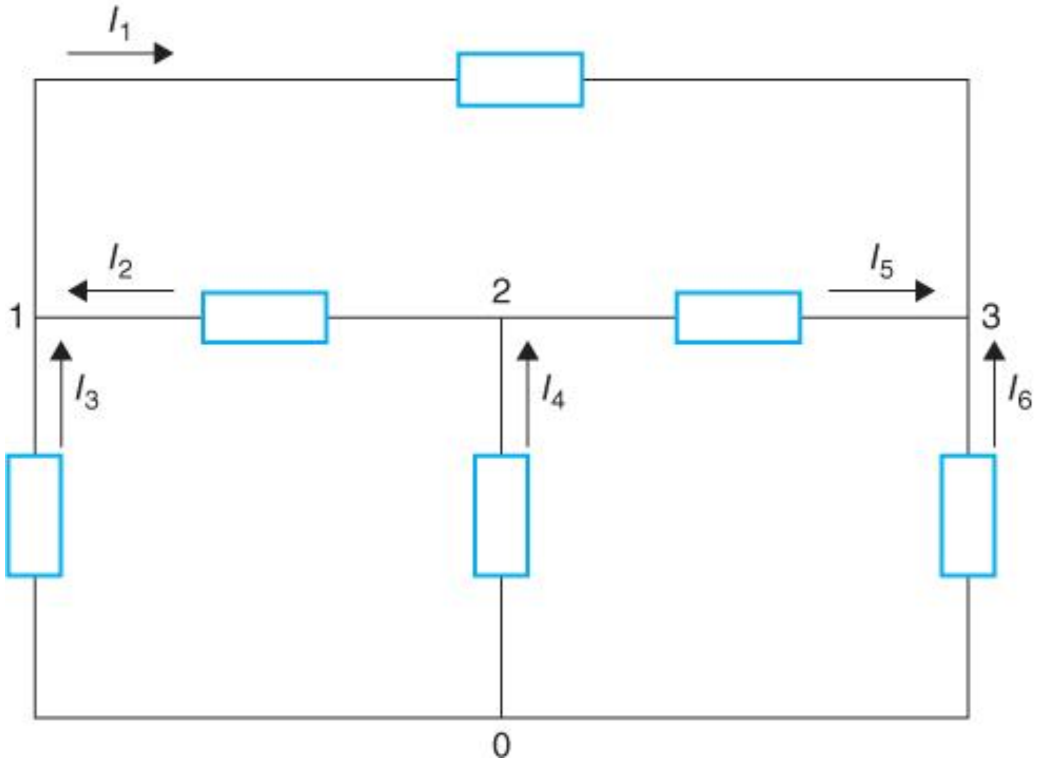
Kirchhoff's Current Law (KCL)

- Example 2.5: Given I_1 = 3 A, I_3 = 10 A, and I_6 = – 8 A, find I_2, I_4, and I_5 in the following circuit.



- KCL at node1: Sum of current entering Node1 =0

  $I_2 + I_3 - I_1 = 0$

  $I_2 = I_1 - I_3 = 3\text{ A} - 10\text{ A} = -7\text{ A}$

- KCL at node3: Sum of current entering Node3 =0

  $I_1 + I_5 + I_6 = 0$

  $I_5 = -I_1 - I_6 = -3\text{ A} - (-8\text{ A}) = 5\text{ A}$

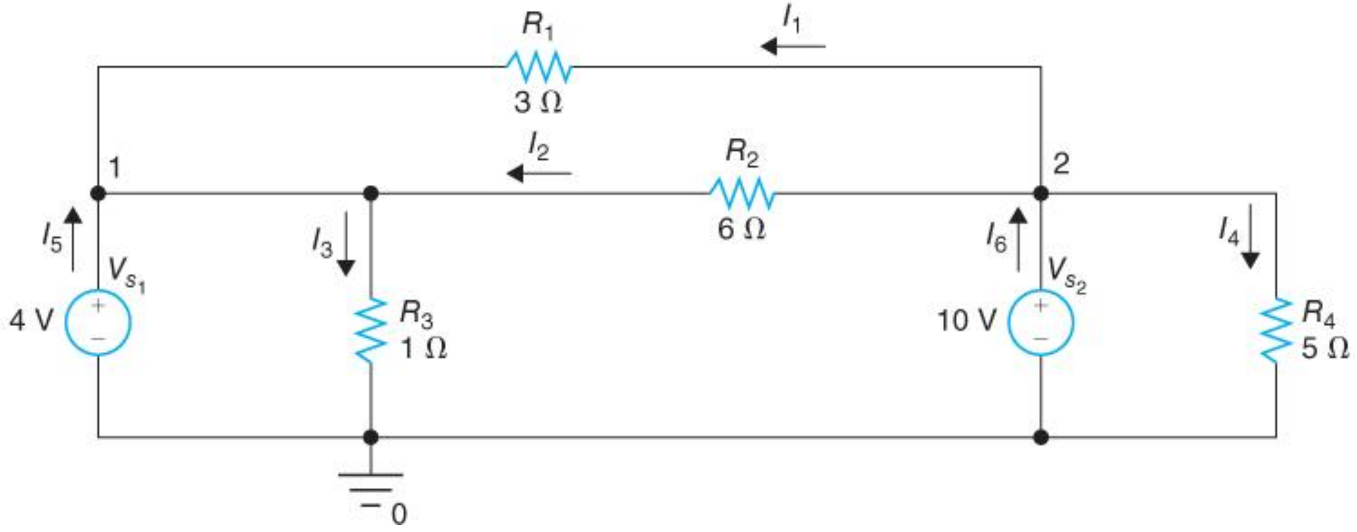
- KCL at node2: Sum of current entering Node2 =0

  $-I_2 + I_4 - I_5 = 0$

  $I_4 = I_2 + I_5 = -7\text{ A} + 5\text{ A} = -2\text{ A}$

Kirchhoff's Current Law (KCL)

❑ **Example 2.6**: Find I_1, I_2, I_3, I_4, I_5, and I_6 in the following circuit.



- Ohm's law: $I_1 = (V_{s2} - V_{s1})/R_1 = 6\ \text{V}/3\ \Omega = 2\ \text{A}$, $I_2 = (V_{s2} - V_{s1})/R_2 = 6\ \text{V}/6\ \Omega = 1\ \text{A}$

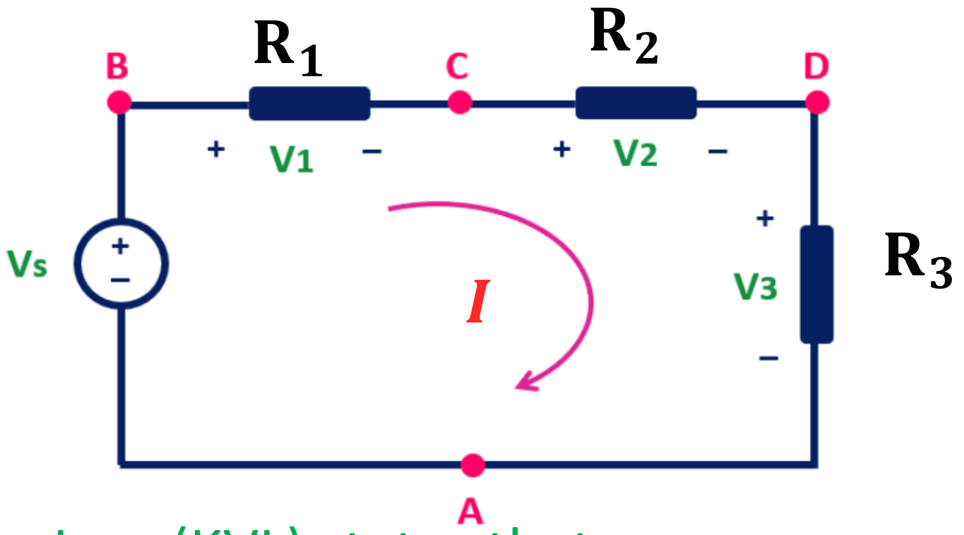
  $I_3 = V_{s1}/R_3 = 4\ \text{V}/1\ \Omega = 4\ \text{A}$, $I_4 = V_{s2}/R_4 = 10\ \text{V}/5\ \Omega = 2\ \text{A}$

- KCL at node1: $I_5 = -I_1 - I_2 + I_3 = -2\ \text{A} - 1\ \text{A} + 4\ \text{A} = 1\ \text{A}$

- KCL at node2: $I_6 = I_1 + I_2 + I_4 = 2\ \text{A} + 1\ \text{A} + 2\ \text{A} = 5\ \text{A}$

Home work: P2.15 to P2.23

Kirchhoff's Voltage Law (KVL)



- Kirchhoff's Voltage Law (KVL) states that

Sum of Voltage Rise in a Loop = Sum of Voltage Drop in a Loop

$$V_s = V_1 + V_2 + V_3$$

- Sign Convention of Elements: (KVL)

Rise in the Potential

Drop in the Potential

Kirchhoff’s Voltage Law (KVL)

- **The sum of voltage drops around a loop equals the sum of voltage rises of the same loop.**
- **The sum of voltage drops around a loop is zero.**
  - At least one of the voltage drops around the loop must be negative (meaning that the voltage actually rises on the branch).
- **The sum of voltage rises around a loop is zero.**
  - At least one of the voltage rises around the loop must be negative (meaning that the voltage actually drops on the branch) for this statement to be true.
- The voltage of a node must be unique, and the voltage for any node cannot have two different values.
- Since a mesh is also a loop, the KVL applies to mesh as well.

Kirchhoff's Voltage Law (KVL)

- Consider a circuit shown in Figure 2.20. We are interested in finding the voltages across the resistors R_1, R_2, and R_3 and the current through them.
  - Ohm's law: $V_1 = R_1 I$, $V_2 = R_2 I$, $V_3 = R_3 I$
  - According to KVL, the sum of voltage drops around the mesh in the clockwise direction is zero:: $-V_s + R_1 I + R_2 I + R_3 I = 0$

$$I = \frac{V_s}{R_1 + R_2 + R_3} = \frac{9}{4000 + 6000 + 8000}\mathrm{A} = 0.5\mathrm{mA}$$

  - Ohm's law: $V_1 = R_1 I = 4000 \times 0.0005\ \mathrm{V} = 2\ \mathrm{V}$

$V_2 = R_2 I = 6000 \times 0.0005\ \mathrm{V} = 3\ \mathrm{V}$

$V_3 = R_3 I = 8000 \times 0.0005\ \mathrm{V} = 4\ \mathrm{V}$

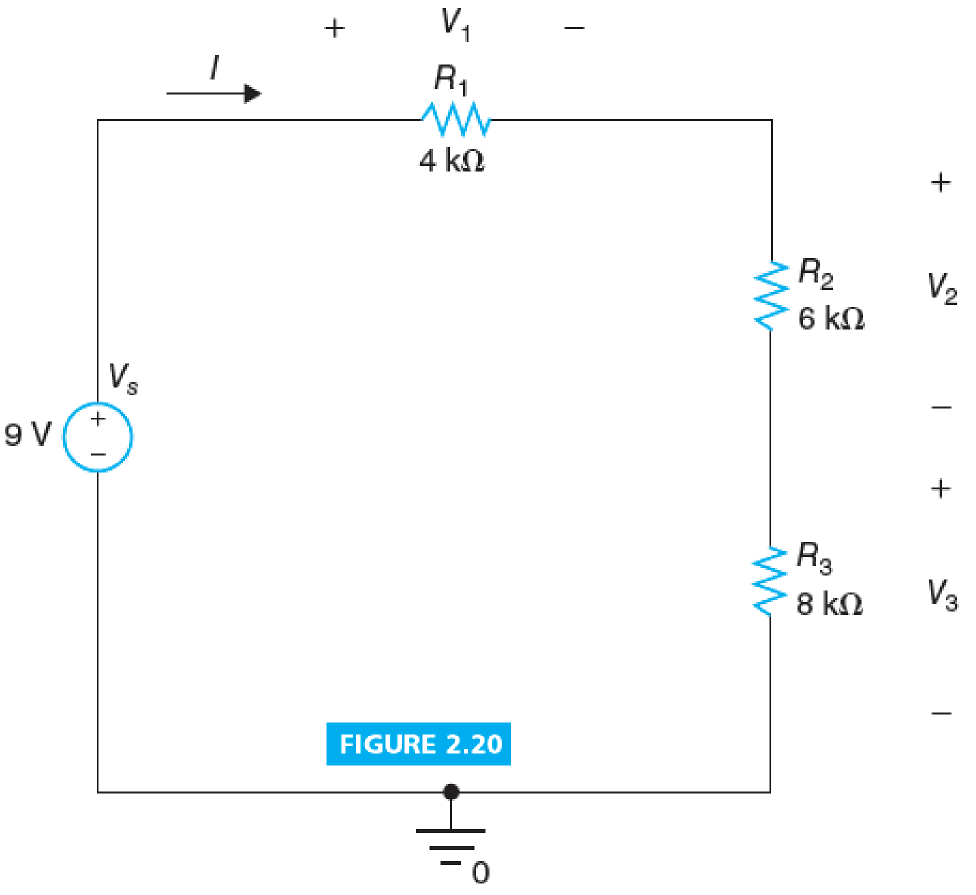


FIGURE 2.20

Kirchhoff's Voltage Law (KVL)

❑ **Example 2.7**: Given V_2 = 6 V, find I_2, I_3, I_4, V_4, I_1, V_1, V_s in the circuit shown in Figure 2.21.

- Ohm's law: $I_2 = V_2/R_2$ = 6/3000 A = 2 mA
  $I_3 = V_2/R_3$ = 6/4000 A = 1.5 mA
- KCL: $I_1 = I_4 = I_2 + I_3$ = 2mA + 1.5mA = 3.5mA
- Ohm's law: $V_4 = R_4 I_4$ = 1000×0.0035 V = 3.5V
  $V_1 = R_1 I_1$ = 600 × 0.0035 V = 2.1V
- KVL: $-V_s + V_1 + V_2 + V_4 = 0$
  $V_s = V_1 + V_2 + V_4$ = 2.1V + 6V + 3.5V = 11.6V

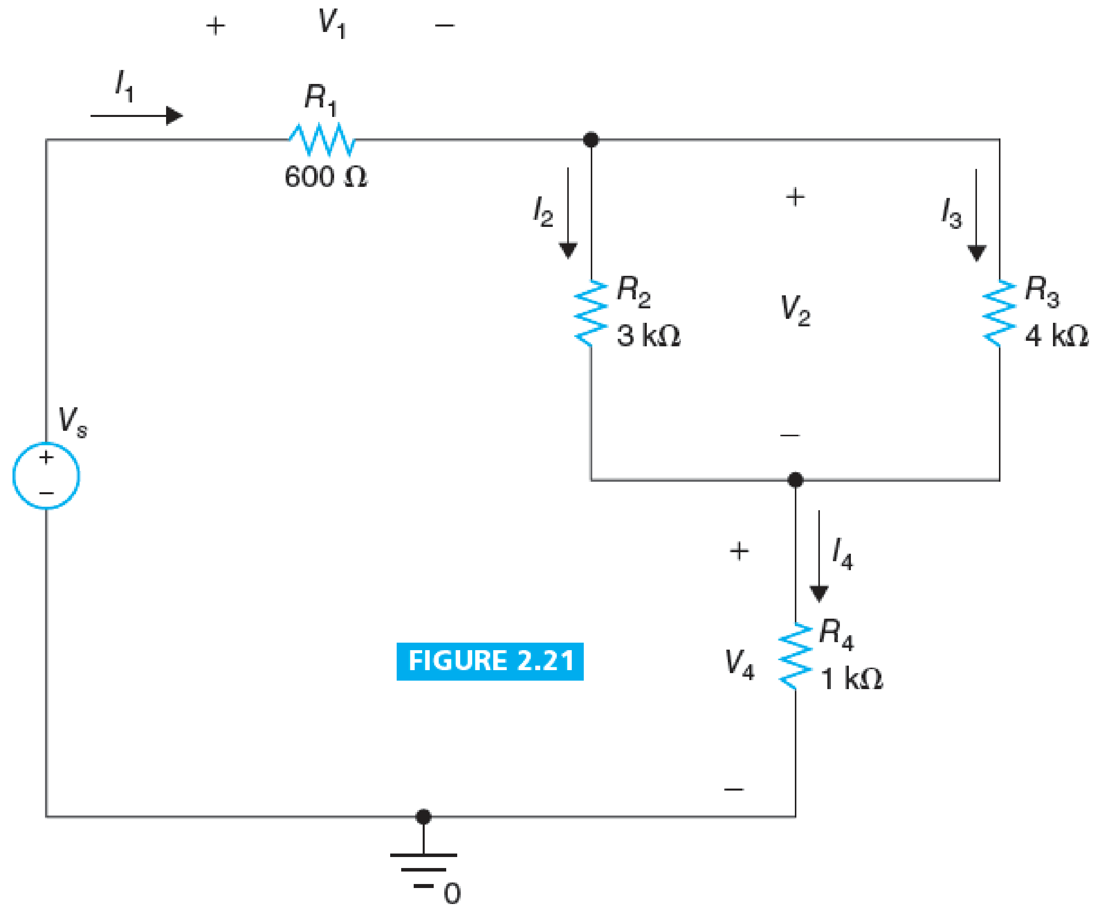


FIGURE 2.21

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Kirchhoff's Voltage Law (KVL)

- **Example 2.8**: Given V_1 = 6 V, V_5 = 5 V, V_6 = 3 V, and V_7 = 7 V, find V_2, V_3, V_4, and V_8 in the circuit shown in Figure 2.23.

What is the value of V4 ?

A. -3 V
B. -4 V
C. -5 V

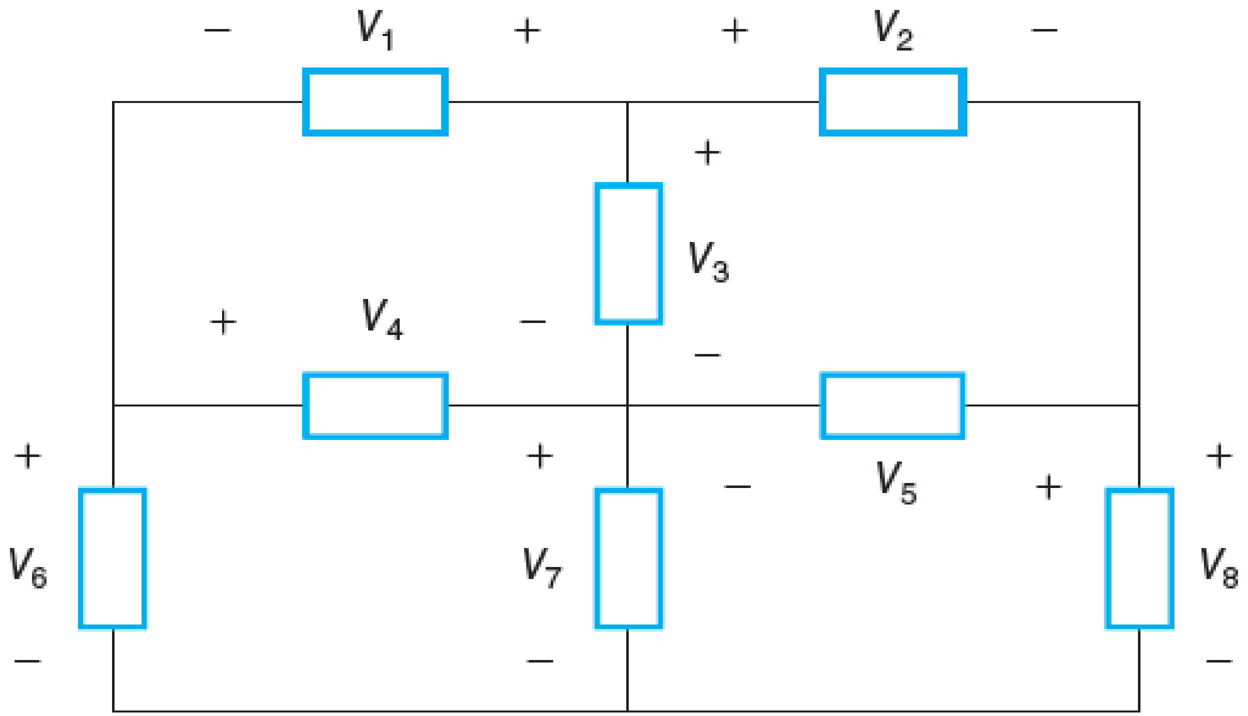

FIGURE 2.23

- The sum of voltage drops around a loop is zero.
- The sum of voltage drops around a loop equals the sum of voltage rises of the same loop.

Solution will be provided in class

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Kirchhoff's Voltage Law (KVL)

- **Example 2.9**: Find i, V_1, V_2, I_2, I_3, I_4, I_5 in the circuit shown in Figure 2.25.

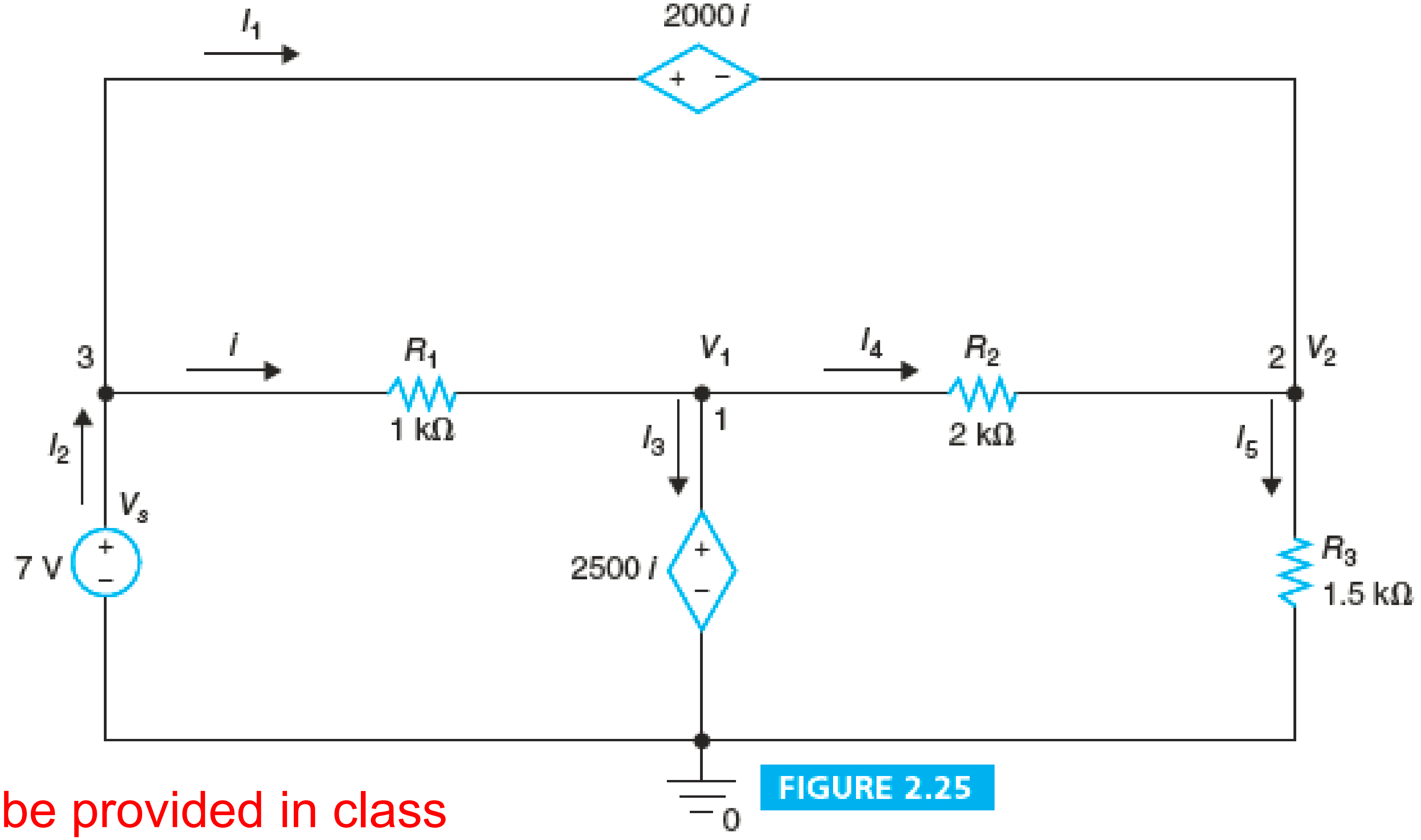


FIGURE 2.25

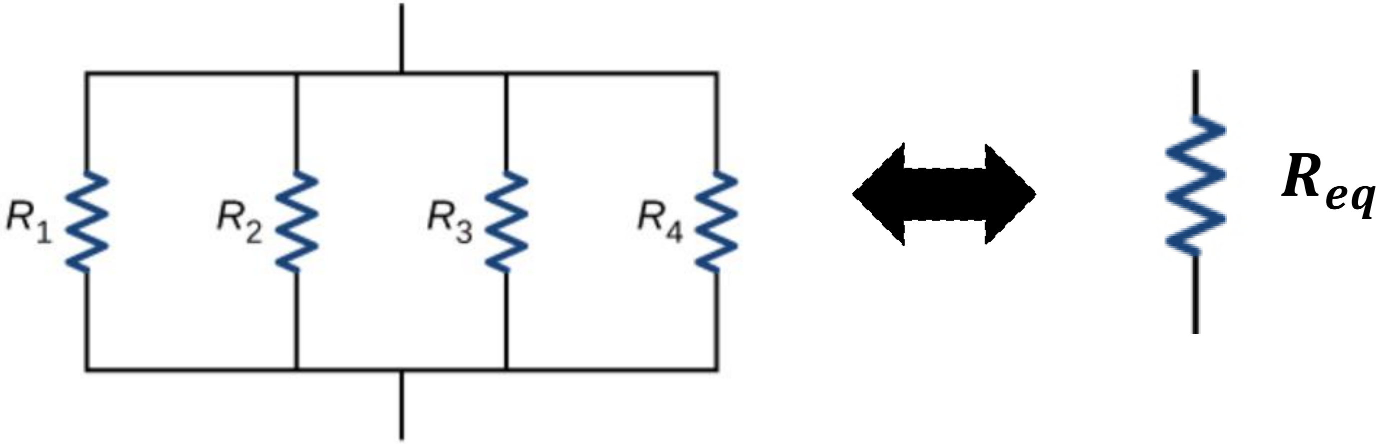
Solution will be provided in class

Equivalent Resistance

❑ **Replacing multiple resistance with one resistor to produce the same impact**

1. **Series Equivalent resistance**

2. **Parallel Equivalent Resistance**



Equivalent Resistance in Series

- Two resistors with resistances R_1 and R_2 are connected in series in Fig.2.27(a).
- Ohm's law: $V_1 = R_1 I$, $V_2 = R_2 I$
- KVL: $-V + V_1 + V_2 = 0$
  $V = V_1 + V_2 = R_1 I + R_2 I = (R_1 + R_2)I = R_{eq} I$
  where R_{eq} is the equivalent resistance of the series connection of R_1 and R_2.
- The circuit shown in Fig.2.27(a) can be replaced by the circuit shown in Fig.2.27(b).
- **If n resistors with resistances R_1, R_2, …, R_n are connected in series, the equivalent resistance is given by: $R_{eq} = R_1 + R_2 + \ldots + R_n$**

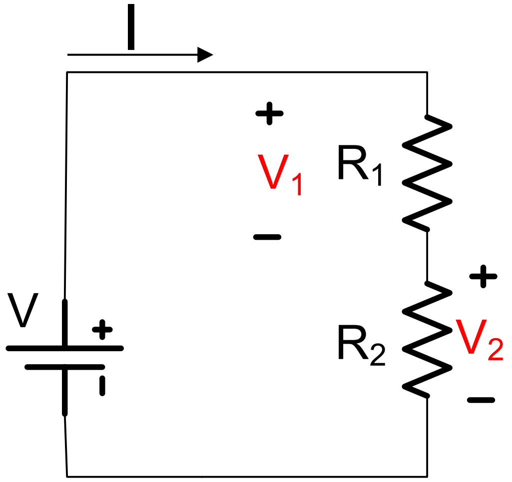


Fig.2.27(a).

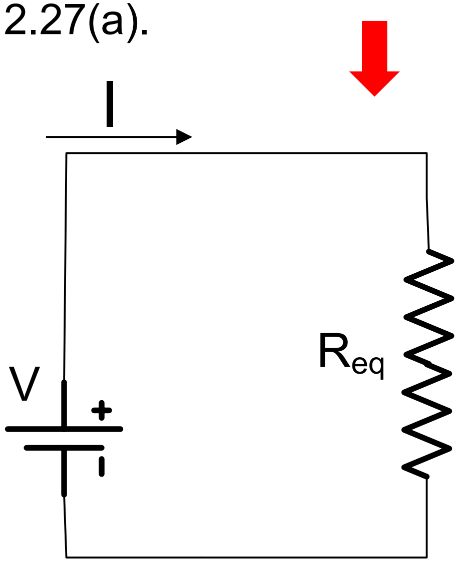


Fig.2.27(b).

Equivalent Resistance in Series

- The equivalent resistance in the series connection of R_1 and R_2 in Fig.2.29 is given by: $R_{eq} = R_1 + R_2 = 25\ k\Omega$
- When R_1 and R_2 are replaced by R_{eq}, we obtain the circuit shown in Figure 2.30.
- Ohm's law: $I = V_s/R_{eq} = 5\ V/25\ k\Omega = 0.2\ mA$
- Ohm's law: $V_1 = R_1 I = 10\ k\Omega \times 0.2\ mA = 2\ V$; $V_2 = R_2 I = 15\ k\Omega \times 0.2\ mA = 3\ V$

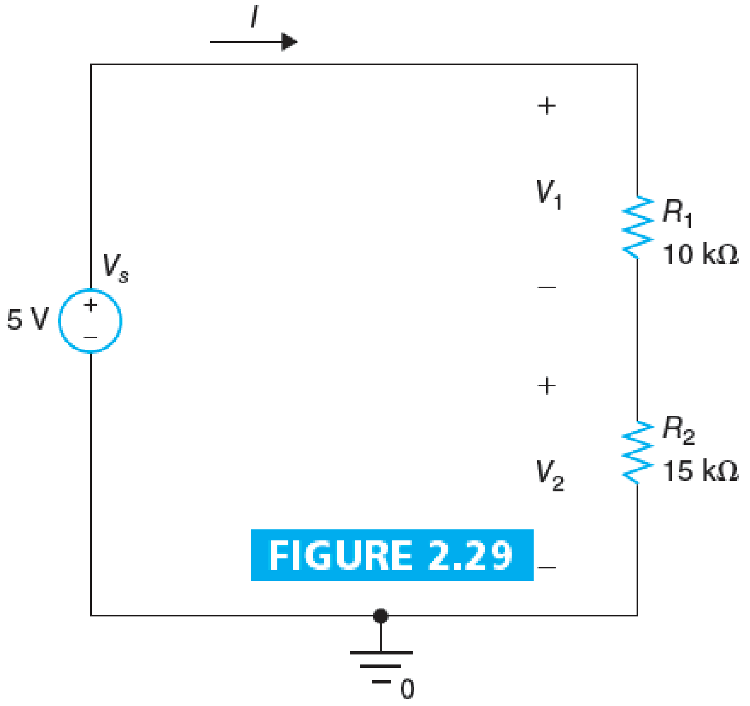


FIGURE 2.29

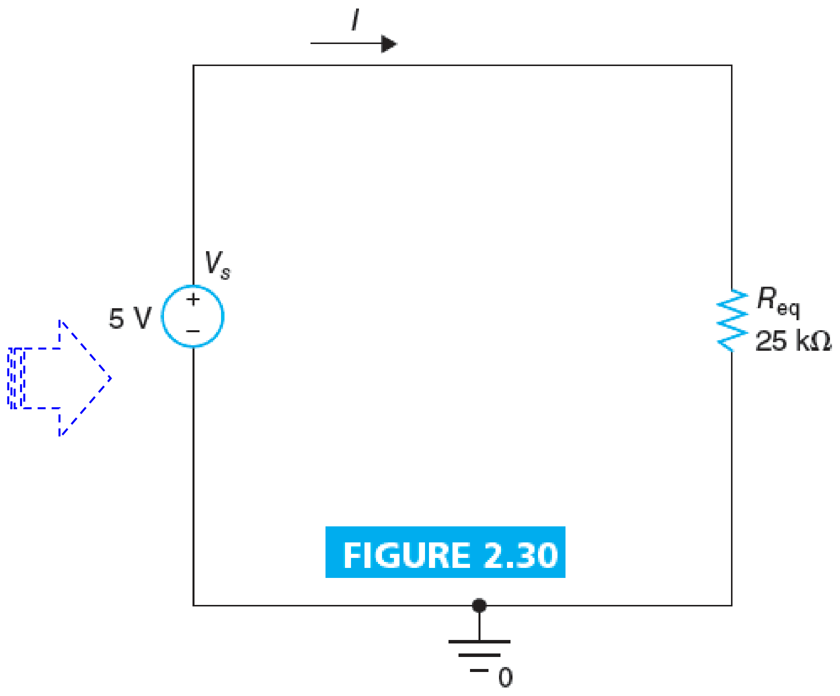


FIGURE 2.30

Equivalent Resistance in Series

- **Example 2.10:** Given I_3 = 750 μA, find V_a, I_2, I_4, I_1, V_s in the circuit shown in Figure 2.31.
  - $R_a = R_2 + R_3 + R_4 = 50\ k\Omega$, $R_b = R_5 + R_6 = 20\ k\Omega$, $R_c = R_7 + R_8 + R_9 + R_{10} = 75\ k\Omega$
  - $V_a = R_b I_3 = 15$ V, $I_2 = V_a/R_a = 0.3$ mA, $I_4 = V_a/R_c = 0.2$ mA, $I_1 = I_2 + I_3 + I_4 = 1.25$ mA
  - $V_1 = R_1 I_1 = 5$ V, $V_s = V_1 + V_a = 20$ V

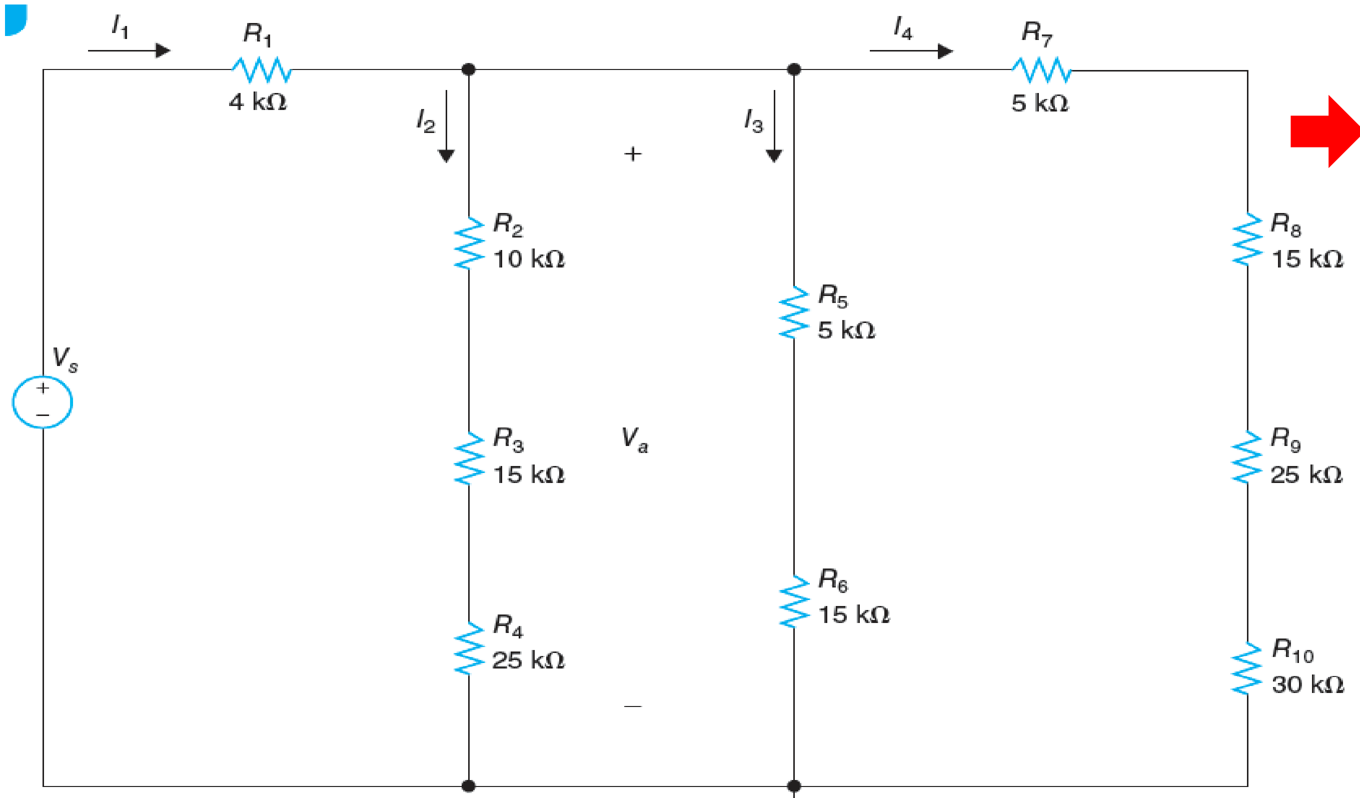


FIGURE 2.31

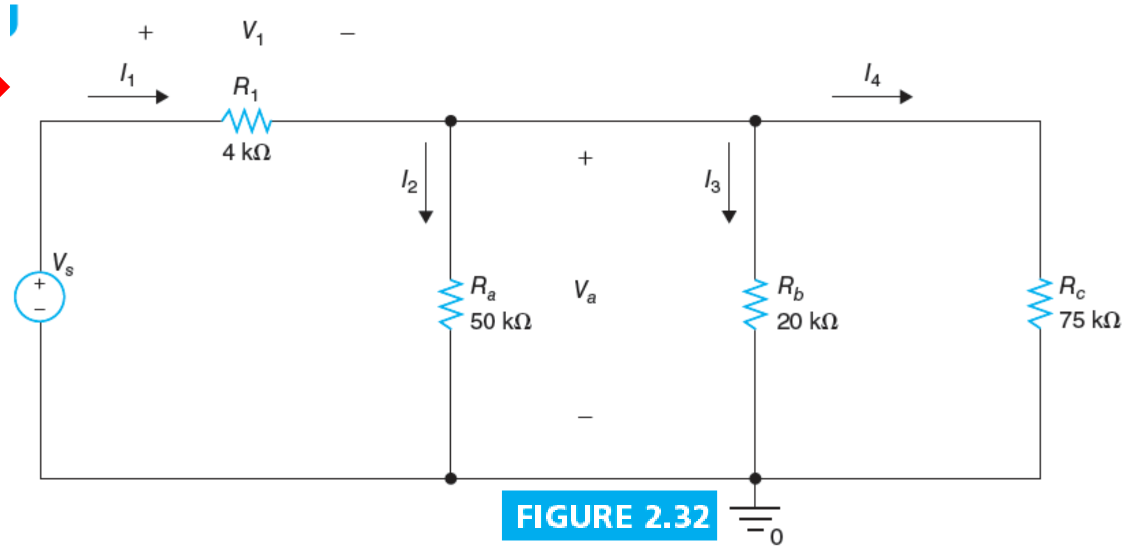


FIGURE 2.32

Figure 2.32 shows simplified circuit.

Equivalent Resistance in Parallel

- Two resistors R_1 and R_2 are connected in parallel as shown in Figure 2.34(a).
- I_1 = current through R_1, I_2 = current through R_2, V = voltage across R_1 and R_2
- KCL:

$$I = I_1 + I_2 = \frac{V}{R_1} + \frac{V}{R_2} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)V \Rightarrow V = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} I = R_{eq} I$$

- The equivalent resistance R_{eq} is given by:

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

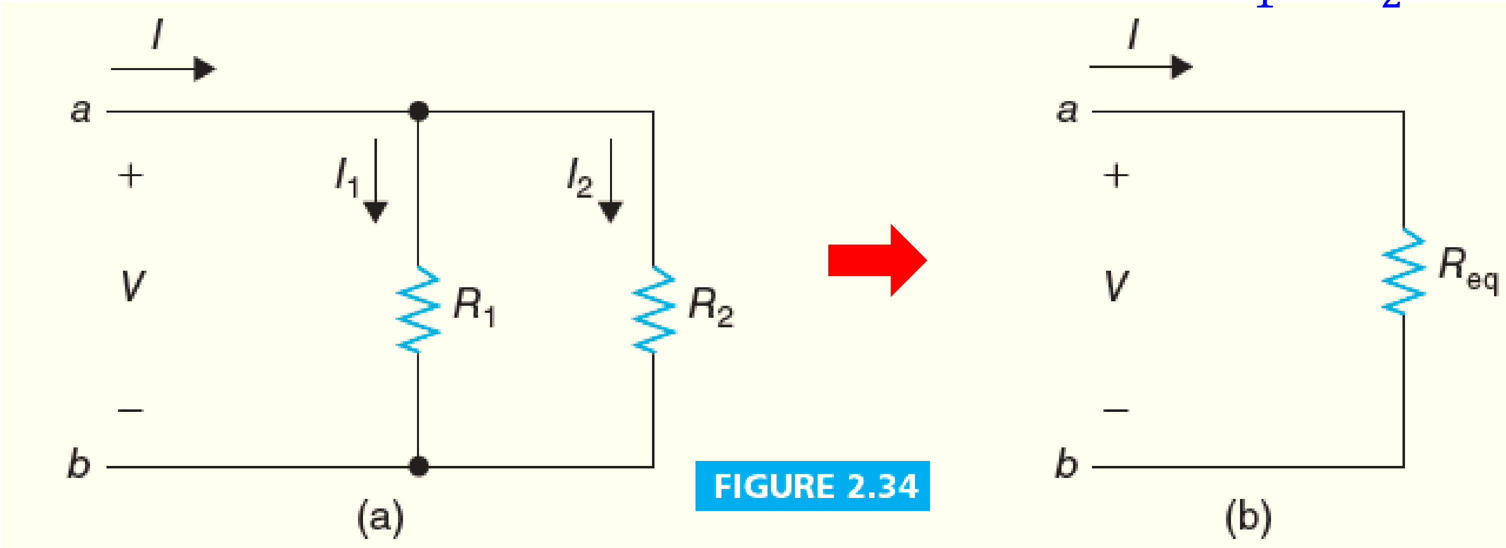
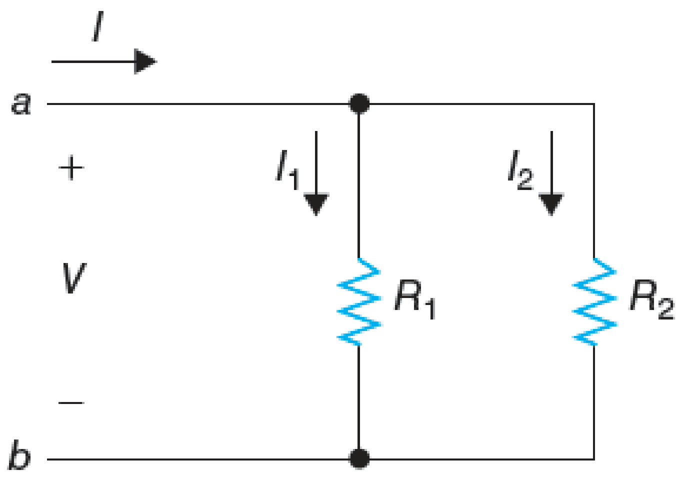


FIGURE 2.34

Properties of R_{eq} = R1 || R2

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

- $R_{eq} < R_1$
- $R_{eq} < R_2$
- The equivalent resistance is smaller than the smallest resistance in parallel.
- $R_1 \,||\, 0 = 0$, $R_1 \,||\, \infty = R_1$.
- If $R_1 << R_2$, $R_1 \,||\, R_2 \approx R_1$.
- If $R_1 = R_2 = R$, $R_1 \,||\, R_2 = R \,||\, R = R/2$.



Equivalent Resistance of n Parallel Resistors

- n resistors $R_1, R_2, \ldots, R_n$ are connected in parallel as shown in Figure 2.35(a).
- I_1 = current through R_1, I_2 = current through R_2, …, I_n = current through R_n
- V = voltage across $R_1, R_2, \ldots, R_n$, equivalent circuit in Figure 2.35(b).
- KCL

$$I = I_1 + I_2 + \ldots + I_n = \frac{V}{R_1} + \frac{V}{R_2} + \ldots + \frac{V}{R_n} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}\right)V$$

$$V = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}} I = R_{eq} I \qquad R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}}$$

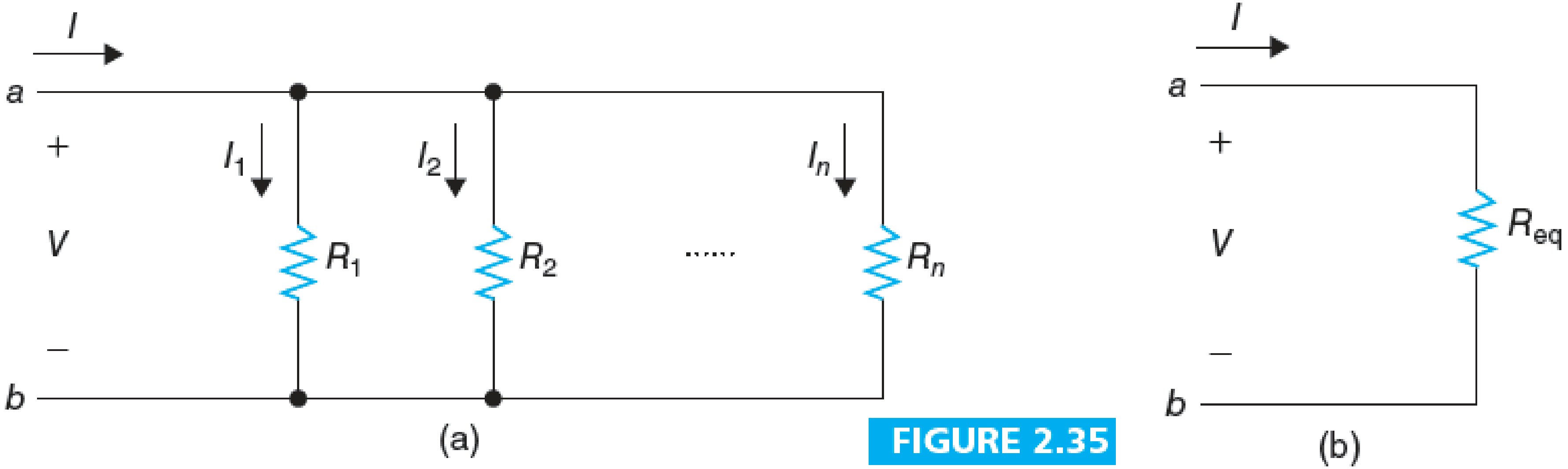


FIGURE 2.35

Circuits with Parallel and Series Resistors

- **Example:** Find I_1, V_1, V_2, I_2, I_3, V_3, I_4, I_5, and I_6 in the circuit shown in Figure 2.36.

$$R_a = R_2||R_3 = \frac{R_2 \times R_3}{R_2 + R_3} = \frac{21k\Omega \times 28k\Omega}{21k\Omega + 28k\Omega} = \frac{588}{49}k\Omega = 12k\Omega$$

$$R_b = R_4||R_5||R_6 = \frac{1}{\frac{1}{33}+\frac{1}{40}+\frac{1}{88}}k\Omega = \frac{1}{0.06667}k\Omega = 15k\Omega \qquad I_1 = \frac{V_s}{R_1 + R_a + R_b} = \frac{15\text{V}}{30k\Omega} = 0.5\text{mA}$$

- $V_1 = R_1 I_1 = 1.5$ V, $V_2 = R_a I_1 = 6$ V, $V_3 = R_b I_1 = 7.5$ V, $I_2 = V_2/R_2 = 0.2857$ mA, $I_3 = V_2/R_3 = 0.2143$ mA, $I_4 = V_3/R_4 = 0.2273$mA, $I_5 = V_3/R_5 = 0.1875$ mA, $I_6 = V_3/R_6 = 0.08523$ mA

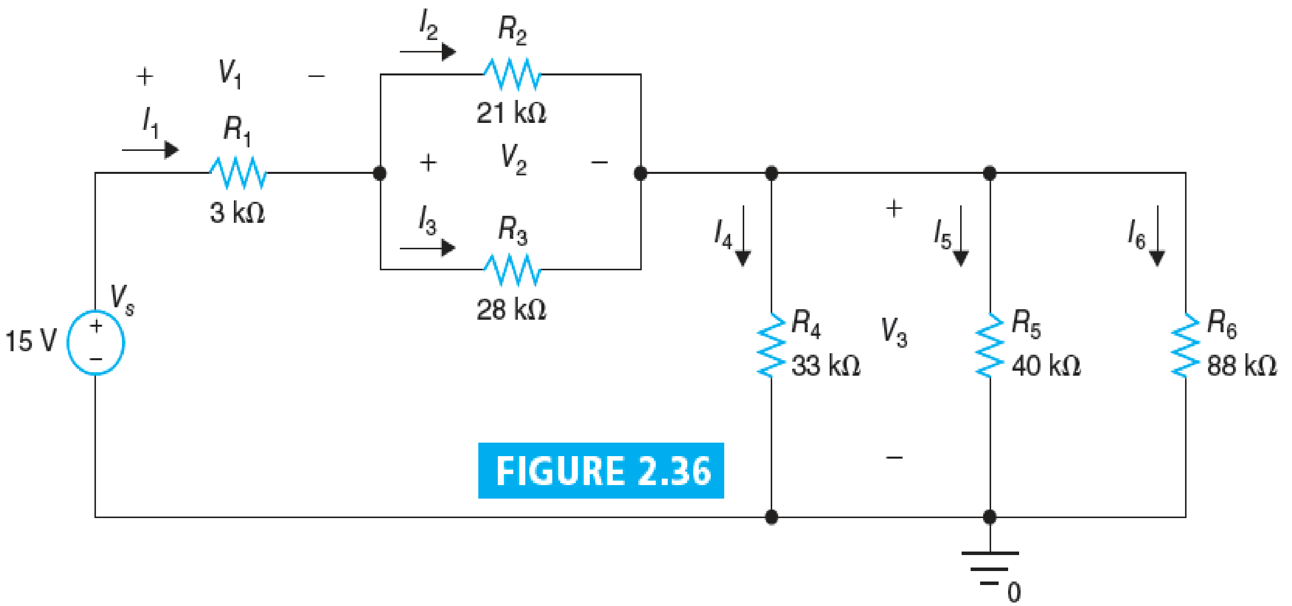
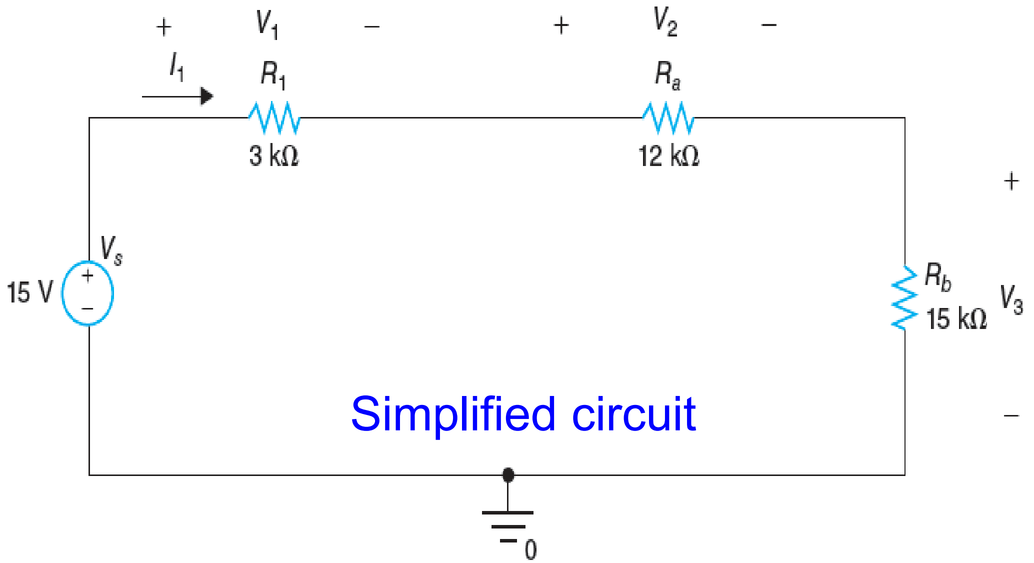


FIGURE 2.36



Simplified circuit

Circuits with Parallel and Series Resistors

- **Example 2.11**: Find the equivalent resistance between terminals *a* and *b* for the circuit shown in Figure 2.38.

$$R_6 = R_4||R_5 = \frac{50\times 75}{50+75} k\Omega = 30k\Omega \qquad R_7 = R_3 + R_6 = 30 + 30\ k\Omega = 60k\Omega$$

$$R_{eq} = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_7}} = \frac{1}{\frac{1}{45}+\frac{1}{90}+\frac{1}{60}} k\Omega = 20k\Omega$$

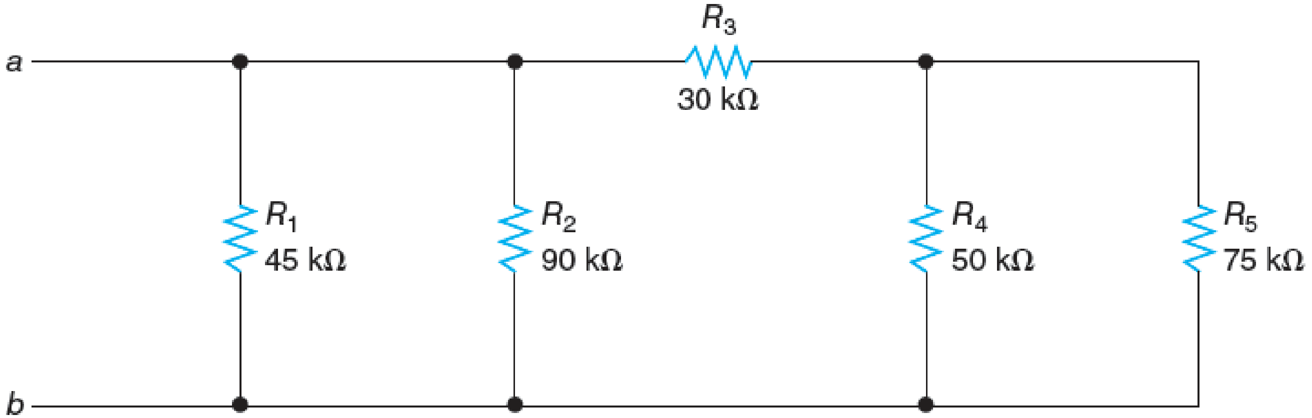


FIGURE 2.38

Circuits with Parallel and Series Resistors

- **Example 2.12:** Find the equivalent resistance seen from the voltage source. Also find I, I_1, I_2, V_1, V_2, V_3, and power absorbed by resistors and power released by the voltage source.
  - $R_a = R_3 \,||\, R_4 = R_3 \times R_4/(R_3+R_4)$ $=100/25\ k\Omega = 4\ k\Omega$
  - $R_{eq} = R_1 + R_2 + R_a = 9\ k\Omega$
  - $I = V_s/R_{eq} = 9/9000\ A = 1\ mA$
  - $V_1 = R_1 I = 2\ V$, $V_2 = R_2 I = 3\ V$, $V_3 = R_a I = 4\ V$
  - $I_1 = V_3/R_3 = 0.8\ mA$, $I_2 = V_3/R_4 = 0.2\ mA$
  - $P_{R1} = IV_1 = 2\ mW$, $P_{R2} = IV_2 = 3\ mW$
  - $P_{R3} = I_1 V_3 = 3.2\ mW$, $P_{R4} = I_2 V_3 = 0.8\ mW$
  - $P_{Vs} = -IV_s = -9\ mW$
  - Power absorbed by resistors = 9 mW
  - Power released by voltage source = 9 mW

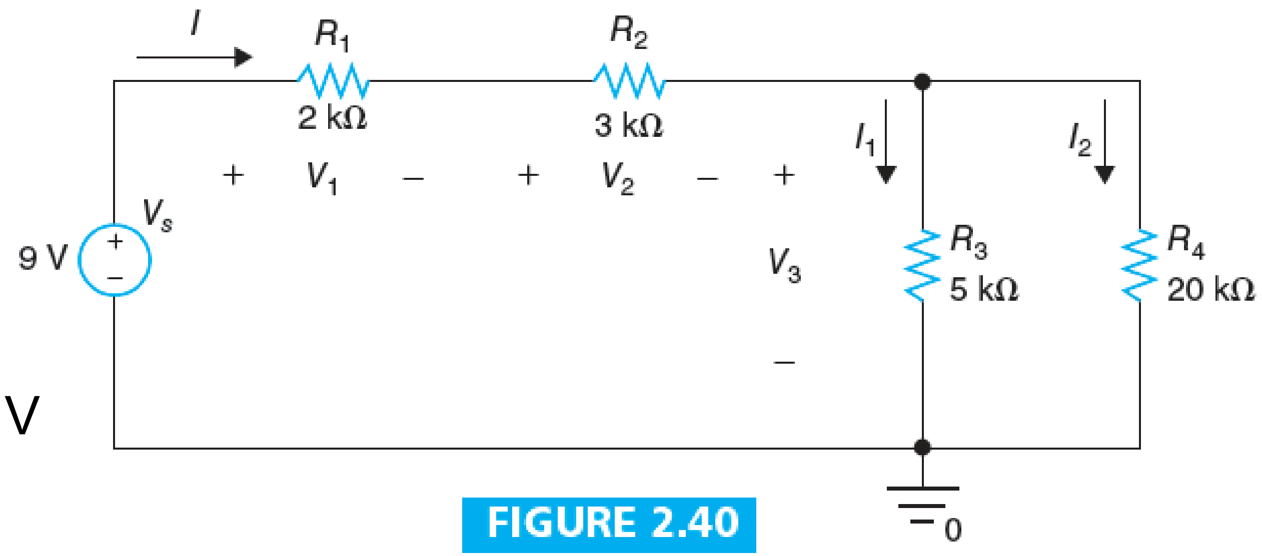


FIGURE 2.40

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Circuits with Parallel and Series Resistors

- **Example 2.13**: Find R_{eq} seen from the voltage source in the circuit shown in Fig.2.43. Also find I_1, I_2, I_3, I_4, I_5, V_1, V_2, V_3, and power absorbed by resistors and power released by the voltage source.
  - $R_a = R_4 \parallel R_5 = R_4 \times R_5/(R_4+R_5) = 24/10\ \text{k}\Omega = 2.4\ \text{k}\Omega$, $R_b = R_3 + R_a = 4\ \text{k}\Omega$
  - $R_c = R_2 \parallel R_b = R_2 \times R_b/(R_2+R_b) = 64/20\ \text{k}\Omega = 3.2\ \text{k}\Omega$, $R_{eq} = R_1 + R_c = 5\ \text{k}\Omega$
  - $I_1 = V_s/R_{eq} = 10/5000\ \text{A} = 2\ \text{mA}$, $V_1 = V_s - R_1 I_1 = 6.4\ \text{V}$, $I_2 = V_1/R_2 = 6.4/16000\ \text{A} = 0.4\ \text{mA}$
  - $I_3 = I_1 - I_2 = 1.6\ \text{mA}$, $V_2 = V_1 - R_3 I_3 = 3.84\ \text{V}$, $I_4 = V_2/R_4 = 3.84/4000\ \text{A} = 0.96\ \text{mA}$, $V_{R5} = V_3$
  - $I_5 = V_2/R_5 = 3.84/6000\ \text{A} = 0.64\ \text{mA}$, $V_{R1} = R_1 I_1 = 3.6\ \text{V}$, $V_{R3} = R_3 I_3 = 2.56\ \text{V}$, $V_{R2} = V_1$, $V_{R4} = V_3$
  - $P_{R1} = I_1 V_{R1} = 7.2\ \text{mW}$, $P_{R3} = I_3 V_{R3} = 4.096\ \text{mW}$, $P_{R2} = I_2 V_{R2} = 2.56\ \text{mW}$
  - $P_{R4} = I_4 V_{R4} = 3.6864\ \text{mW}$
  - $P_{R5} = I_5 V_{R5} = 2.4576\ \text{mW}$
  - $P_{Vs} = -I_1 V_s = -20\ \text{mW}$
  - Power released = 20 mW
  - Power absorbed by resistors = 20 mW

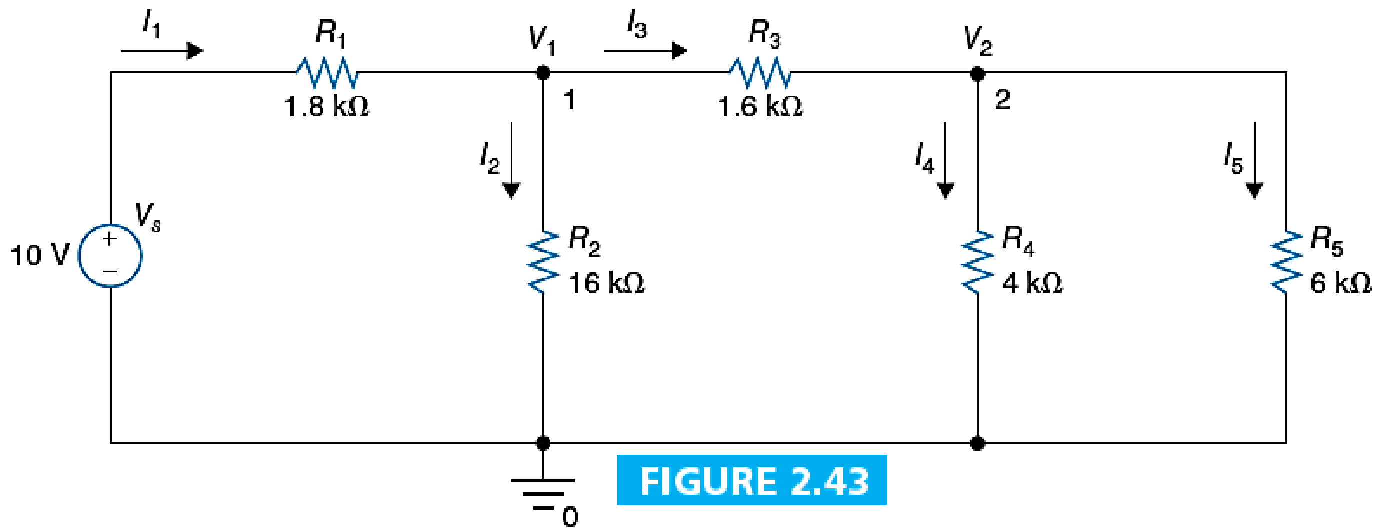
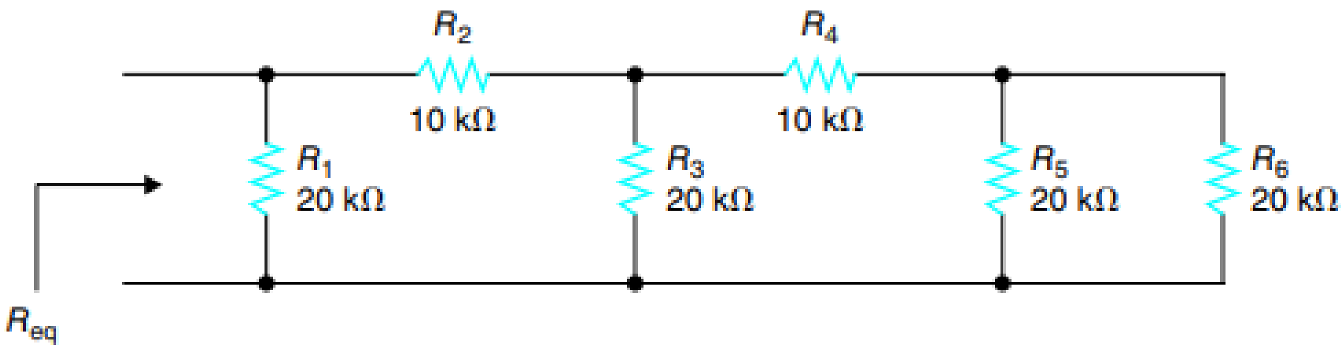


FIGURE 2.43

Problem 2.39

FIGURE P2.39



Fill in the Blanks

- **What is the value of equivalent resistance --------------------------**

Solution will be provided in class

Circuits with Parallel and Series Resistors

- **Example 2.14**: Find the equivalent resistance seen from the current source. Also find I_a, I_1, I_2, I_3, I_4, I_5, I_6, I_7, V_1, V_2, V_3 for the circuit shown in Figure 2.46.

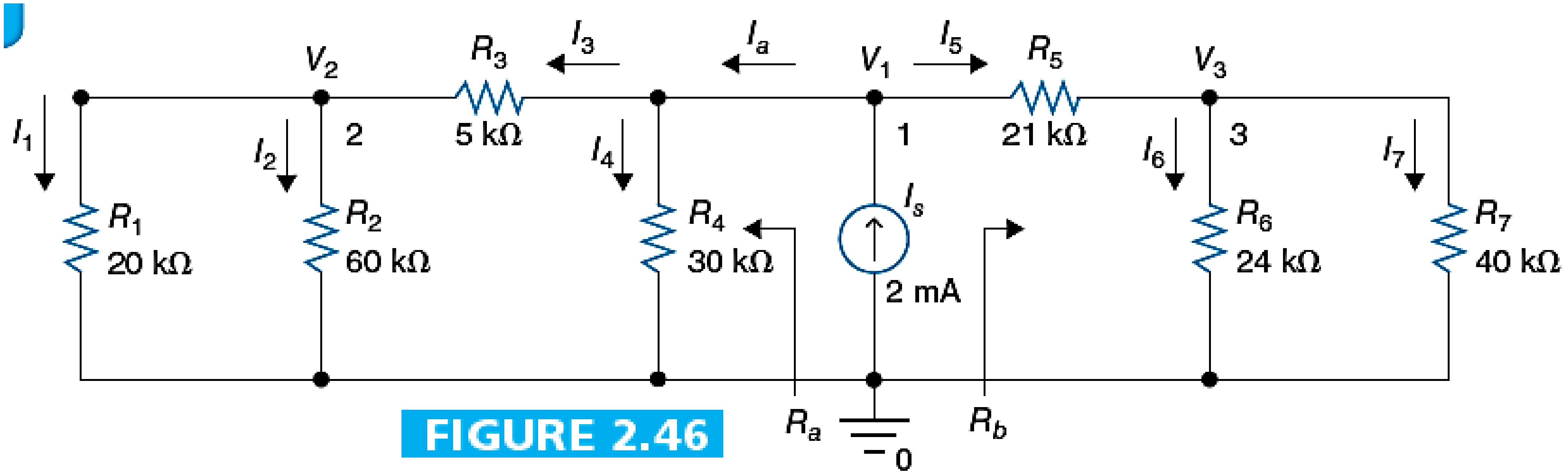


FIGURE 2.46

Solution will be provided in class

Home practice P 2.32 to P 2.46

Summary

- Definition of node, branch, path, loop, and mesh
- Resistor, Ohm’s law
- KCL and KVL
- Equivalent resistance of series connection of resistors
- Equivalent resistance of parallel connection of resistors
- What will we study in next lecture.