FALL 2026 | MEE4033

Mechatronics

Mechatronics (MEE4033) · Department of Mechanical Engineering

Lecture 2

Circuit Basic 1 — Fundamentals of Electric Circuits

Principles and Applications of Electrical Engineering, 7th ed., Chapter 1
Electric Circuits, 11th ed., Chapters 1–2

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1.1 Features of Networks and Circuits (1)

Two principal quantities in circuits.

- Current.
- Voltage.

Objective of circuit analysis.

- Determine unknown currents and voltages.

Key concepts.

- Source and load.
- Ideal wire.
- Node, branch, loop, and mesh.

1.1 Features of Networks and Circuits (2)

Source.

- Provides energy.

Load.

- Consumes energy for some purpose.

Ideal wire.

- Conducts electric charge without any loss of potential.
- Good approximation in many applications.
  - Poor approximation for long-distance transmission lines and microscopic ICs.

Nodes

One or more ideal wires connected together.

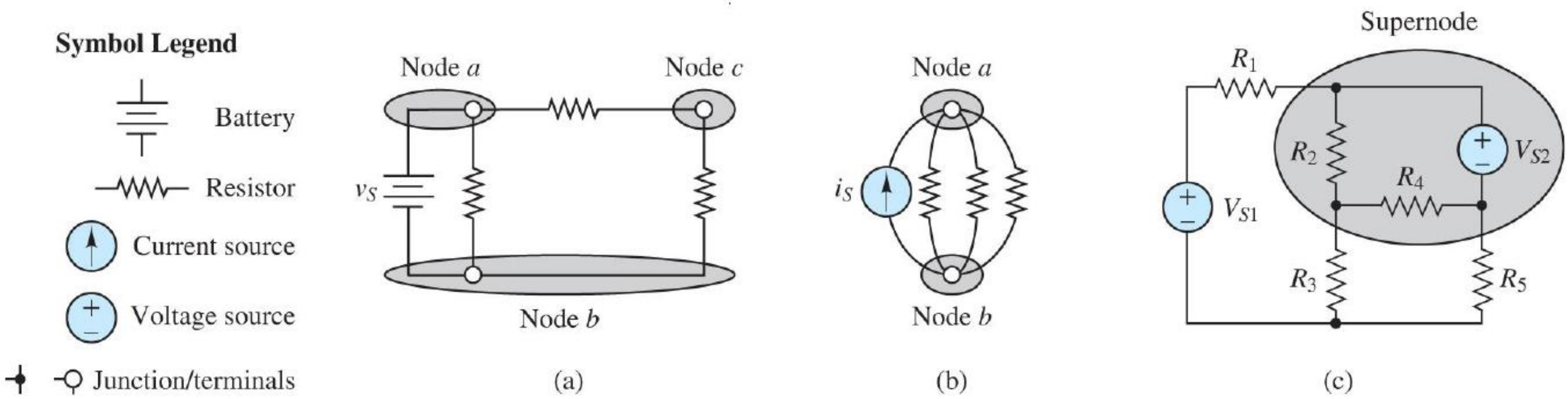
Every point on a node has same electric potential.

Select a reference node.

- Node voltage is relative to the reference node.

Same symbol used for reference node as for earth ground.

Illustrating Nodes and Supernodes in Circuit Diagrams



1.1 Features of Networks and Circuits (3)

Branch.

- Single electrical pathway.
- Consists of wires and elements.
- Elements of a branch said to be in series.

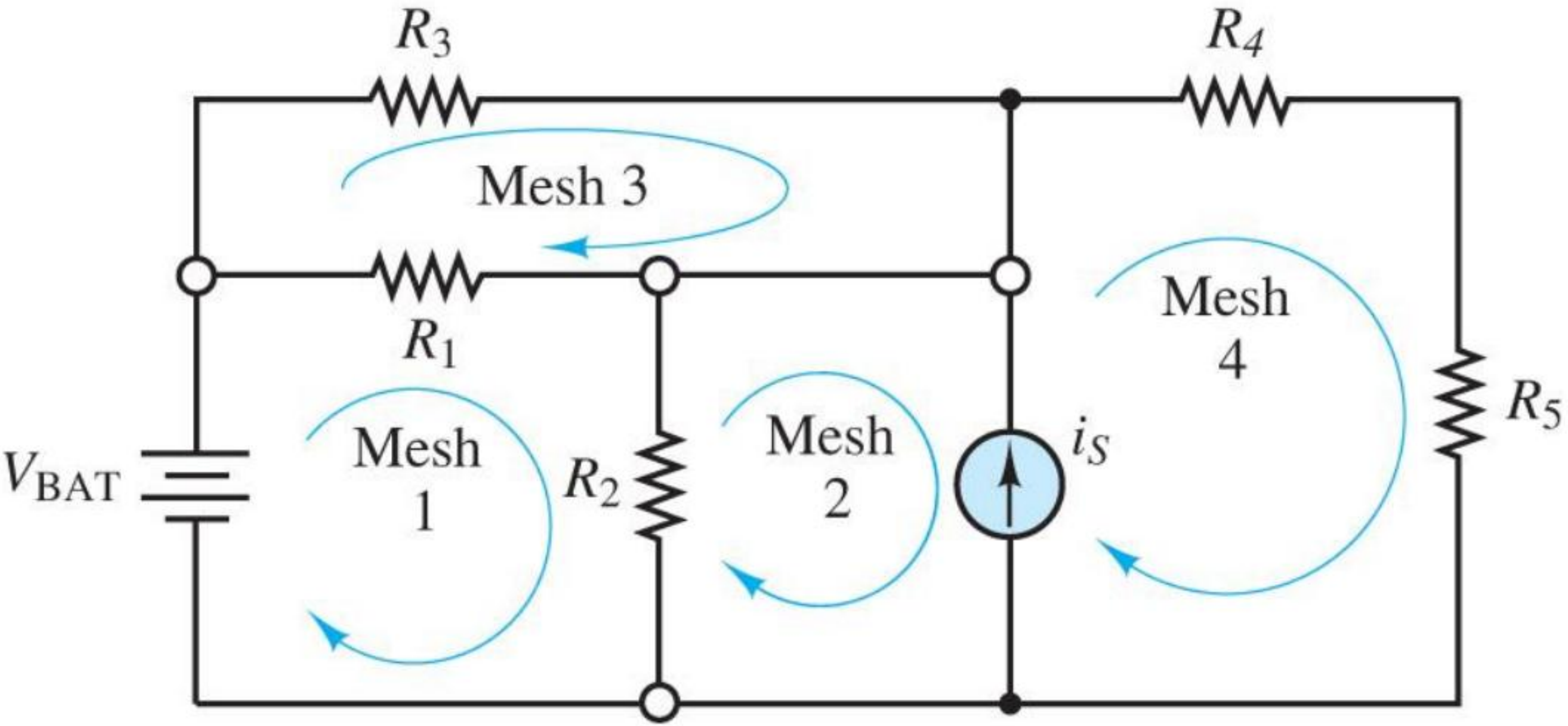
Loop.

- Any closed pathway, physical or conceptual.

Mesh.

- Closed electrical pathway not containing other closed physical pathways.

Circuit with Four Meshes



1.2 Charge, Current, and Voltage

Electric current.

- Rate at which charge passes through a predetermined area.
- Unit is the ampere (A).

Arrow symbol indicates assumed direction of current i.

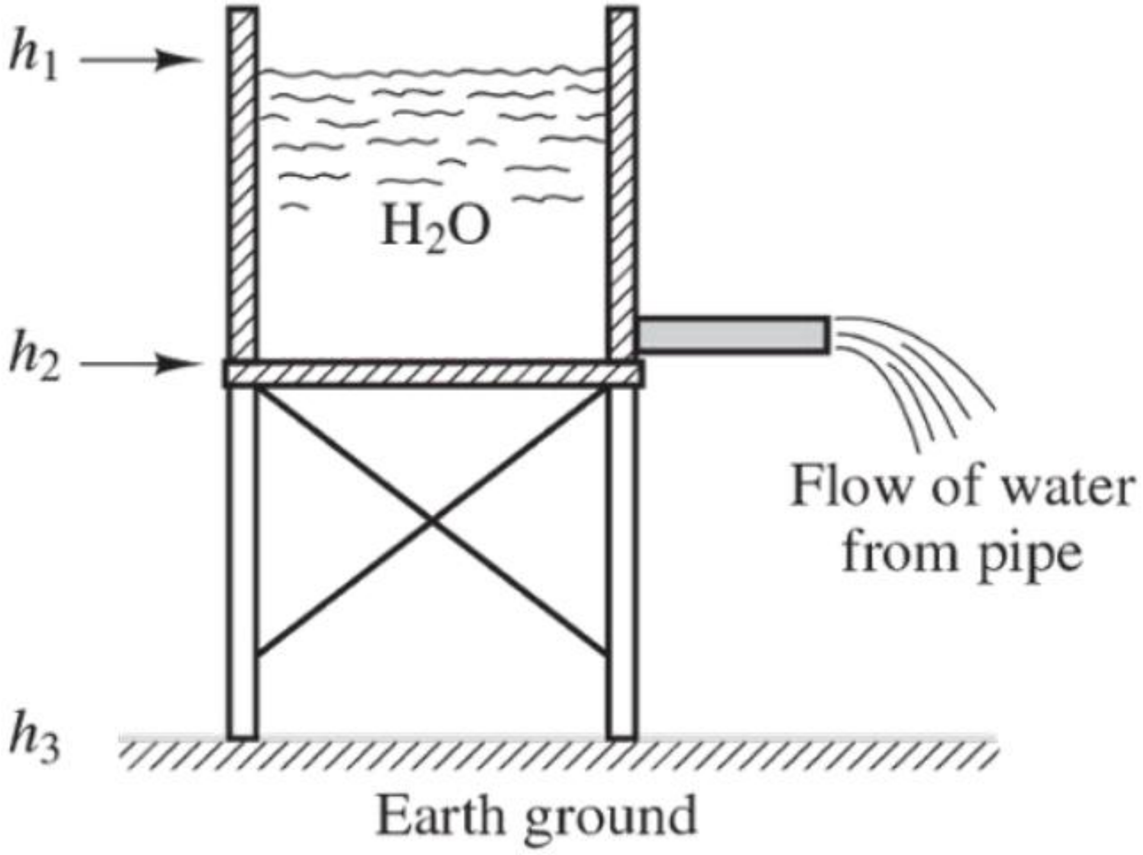
Closed electrical path required for nonzero current.

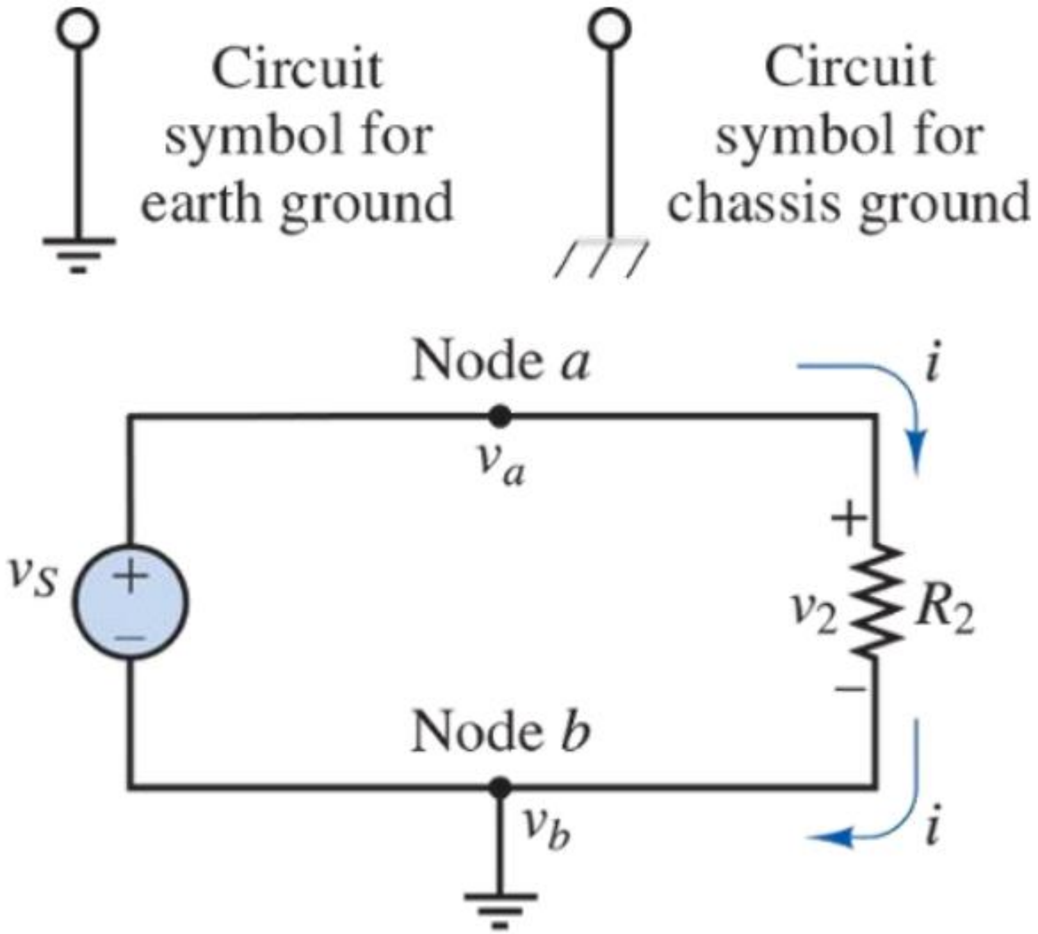
Voltage

Voltage: amount of work per charge.

- Units of volts (V).
- Also called potential difference.
- Direction (polarity) indicates whether energy is gained or lost by the charge.

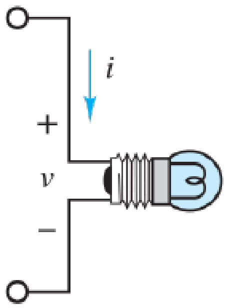
Potential Difference and Ground Reference Potential



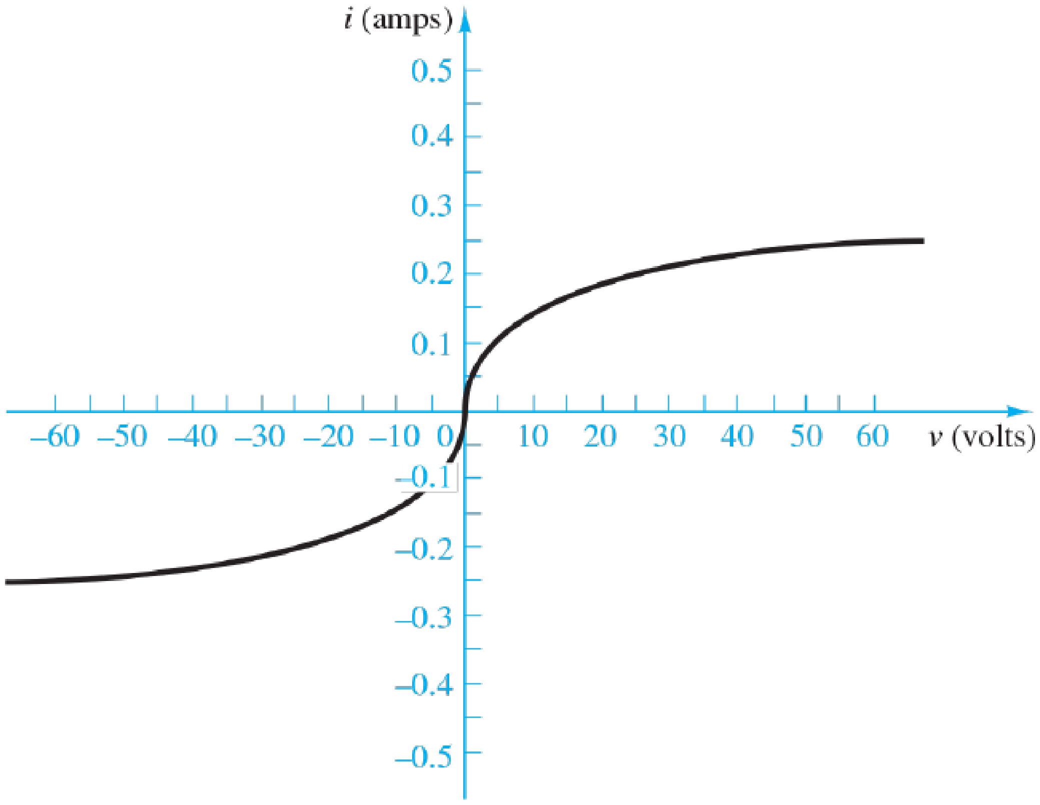


1.3 i-v Characteristics and Sources

- Plot of the i-v characteristic for most circuit elements is either known or can be determined experimentally.



(a)

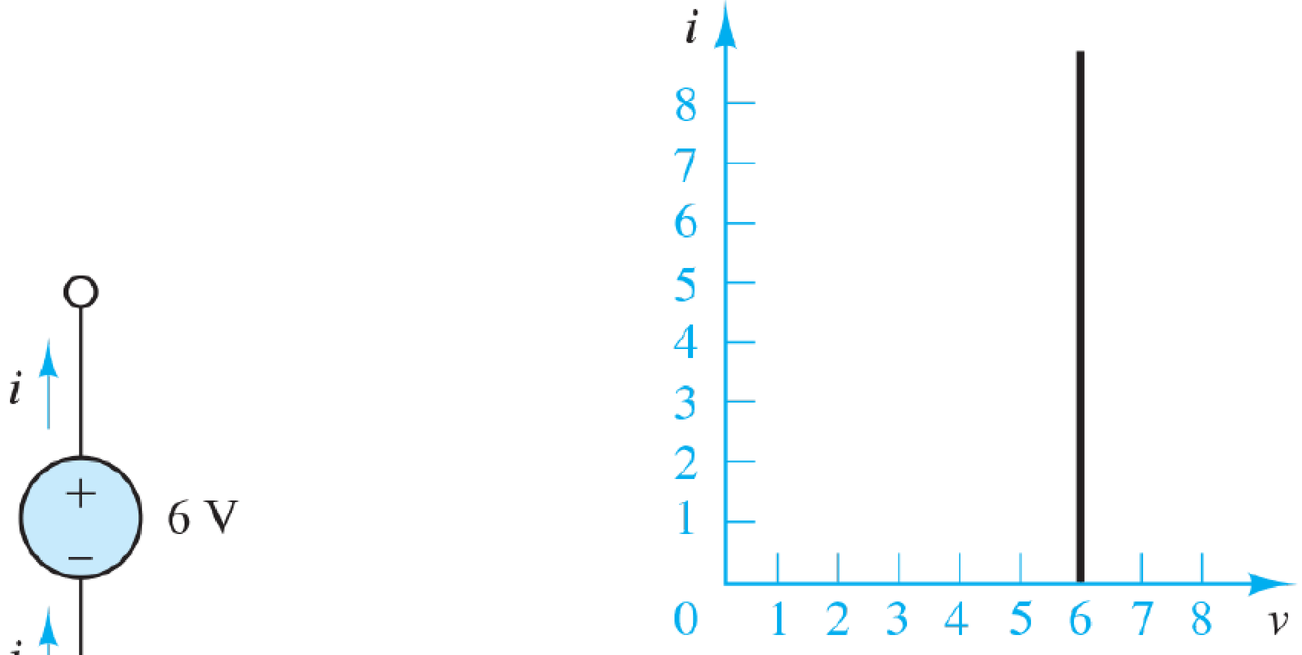


(b)

Ideal Voltage Sources

Generated voltage independent of the current.

- Amount of current determined by the circuit connected to the voltage source.



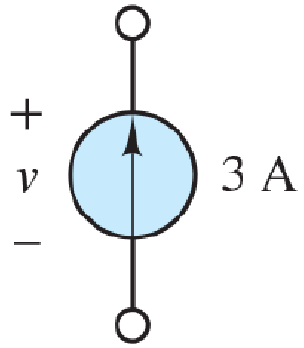
i-*v* characteristic
of a 6 V voltage source

(a) (b)

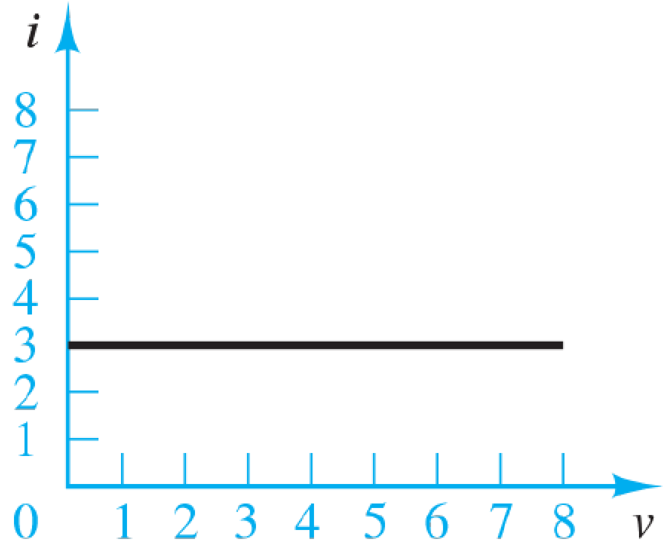
Ideal Current Sources

Generated current independent of the voltage across its terminals.

- Amount of voltage determined by the circuit.



(a)



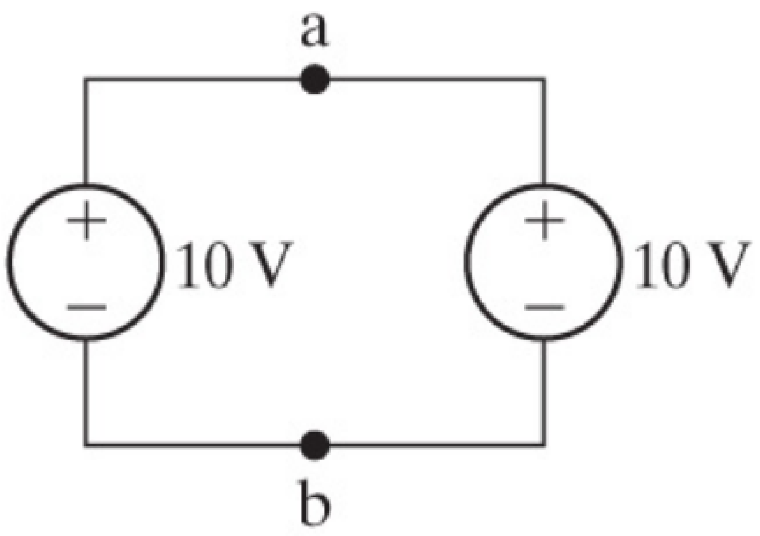
i-*v* characteristic
of a 3-A current source

(b)

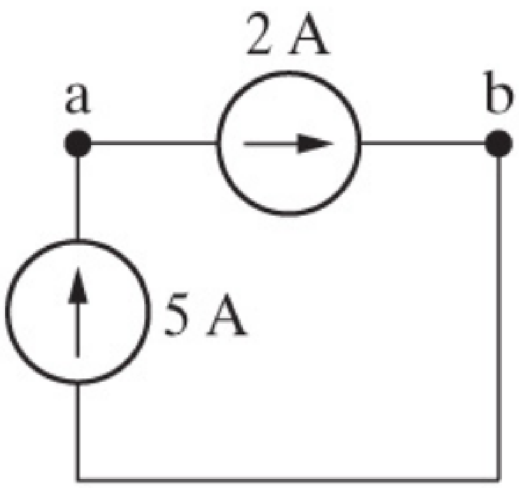
Ideal Voltage/Current Sources

Interconnected sources

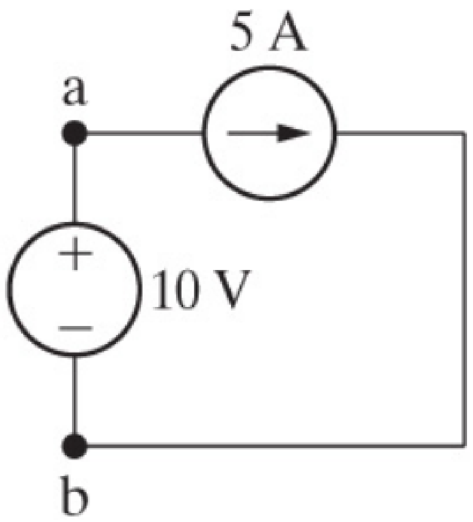
- When ideal sources are connected together to form a circuit, the connection is valid only if the constraints imposed by the ideal sources are not violated.



Valid or invalid?



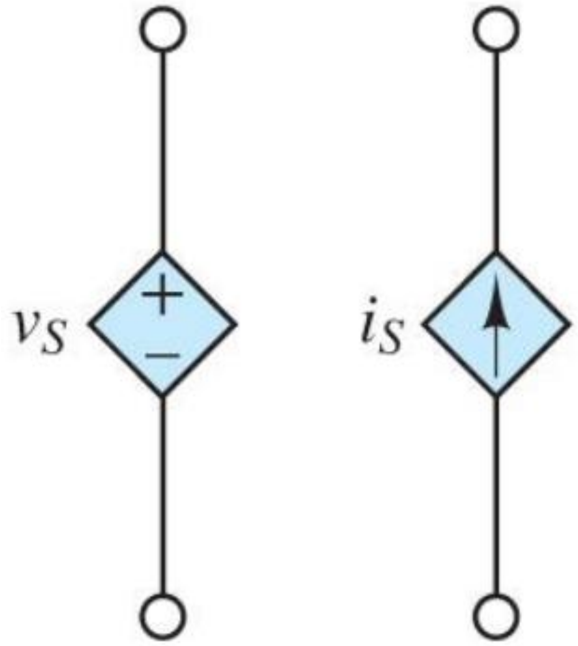
Valid or invalid?



Valid or invalid?

Dependent (Controlled) Sources

- Output depends on some other voltage or current within the circuit.

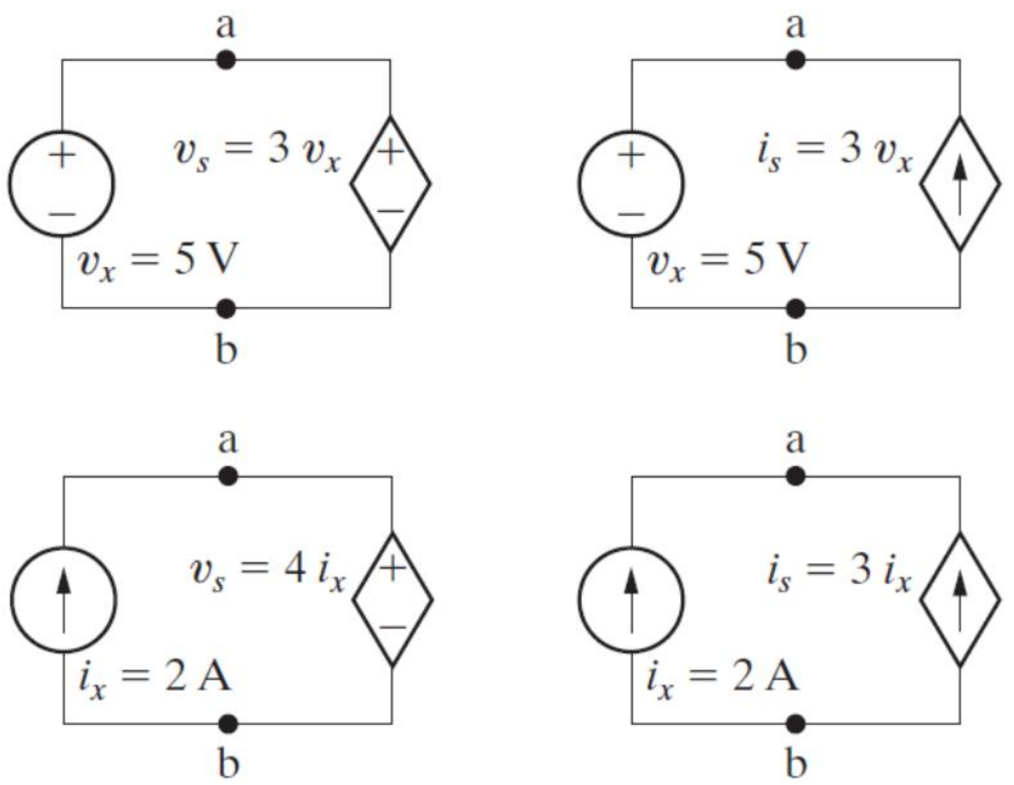


Source type	Relationship
Voltage controlled voltage source (VCVS)	$v_S = \mu v_x$
Current controlled voltage source (CCVS)	$v_S = r i_x$
Voltage controlled current source (VCCS)	$i_S = g v_x$
Current controlled current source (CCCS)	$i_S = \beta i_x$

Examples — Interconnected Sources

Interconnected sources

- When ideal sources are connected together to form a circuit, the connection is valid only if the constraints imposed by the ideal sources are not violated.



1.4 Power and the Passive Sign Convention (1)

Electric power.

- Work per unit time.
- Product of voltage across an element and current through it.
- Units of watts (W).

1.4 Power and the Passive Sign Convention (2)

Passive elements do not require an external energy source.

- Examples: resistors, capacitors, electric motors.

Using the Passive Sign Convention

Figure 1.5 ▲ An ideal basic circuit element.

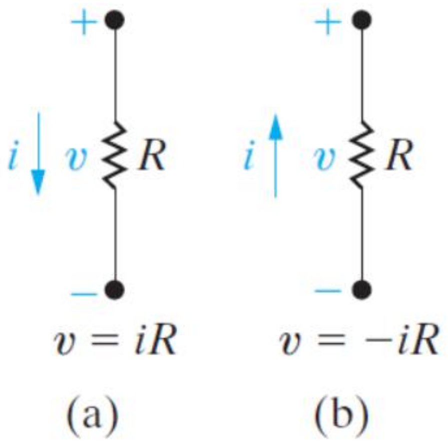


Figure 2.6 ▲ Two possible reference choices for the current and voltage at the terminals of a resistor and the resulting equations.

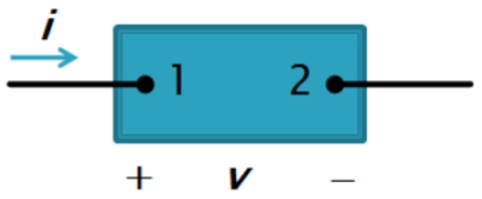
PASSIVE SIGN CONVENTION

Whenever the reference direction for the current in an element is in the direction of the reference voltage drop across the element (as in Fig. 1.5), use a positive sign in any expression that relates the voltage to the current. Otherwise, use a negative sign.

Using the Passive Sign Convention

- **Power**
  - **Actually,** $\boxed{p = \pm vi}$

    How do you know which sign to use???
  - **Use passive sign convention**



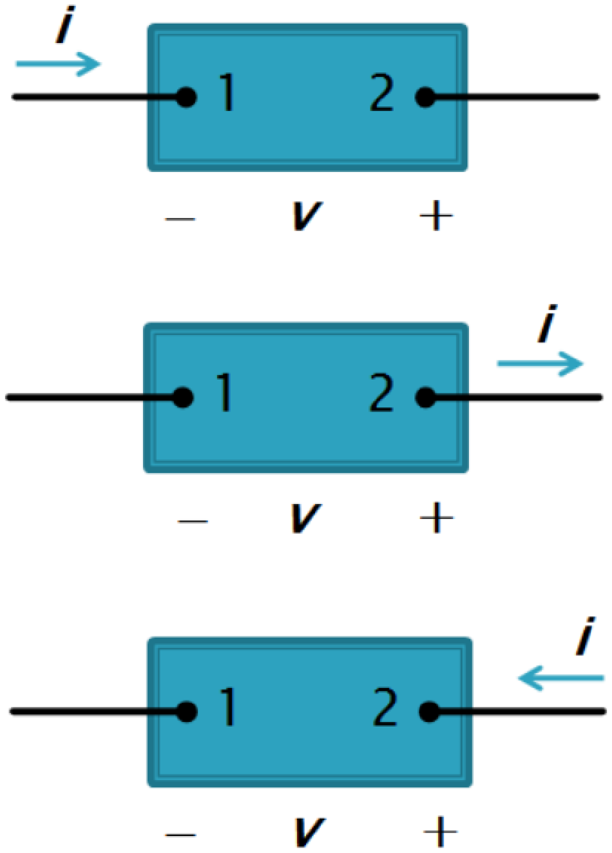
If the current arrow points to the + terminal of the voltage, use a + sign in the equation. Otherwise, use a − sign.

For the ideal basic circuit element above,

$$p = +vi = vi$$

Using the Passive Sign Convention

- **Passive sign convention example:**



$$p = -vi$$

$$p = -vi$$

$$p = +vi = vi$$

Computing the Power Associated with Each Element

For passive elements:

- Power is positive and equal to vi.

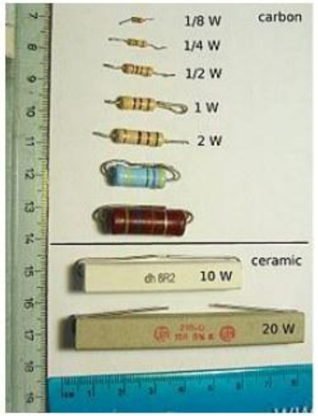
For active elements:

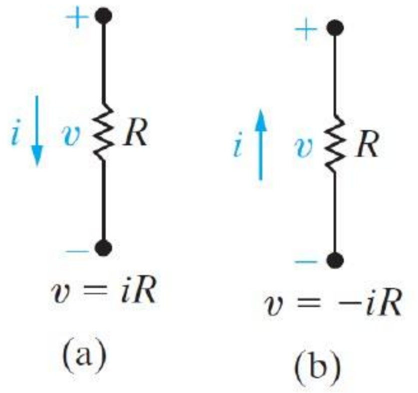
- Power is usually negative and equal to −vi.

Positive power indicates energy is dissipated or stored.

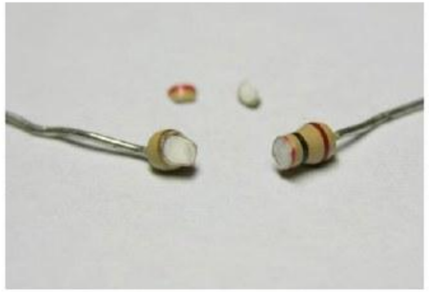
Negative power indicates energy is supplied or released.

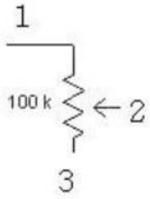
Resistor





https://en.wikipedia.org/wiki/Resistor#/media/File:Electronic-Axial-Lead-Resistors-Array.jpg





OHM'S LAW

$$v = iR,$$

- R (symbol), Ω (Unit)
- Capacity of material to impede the flow of current
- Caused by interaction and restriction between the electric current and atomic structure of the material → heat dissipation

Resistor

- Assuming the resistance of the ideal resistor is constant
- Most actual resistive devices have a time-varying resistance

$$p = vi = (iR)i.$$

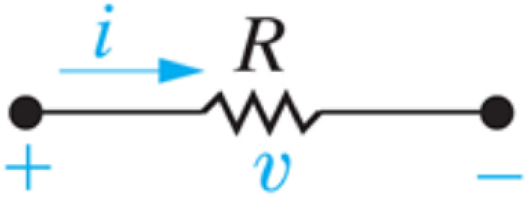
POWER IN A RESISTOR IN TERMS OF CURRENT

$$p = i^2R. \tag{2.8}$$

POWER IN A RESISTOR IN TERMS OF VOLTAGE

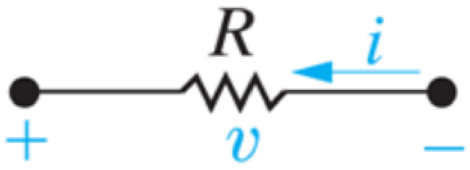
$$p = \frac{v^2}{R}. \tag{2.10}$$

Resistor



$$p = +vi = (Ri)i$$
$$= Ri^2 > 0!$$

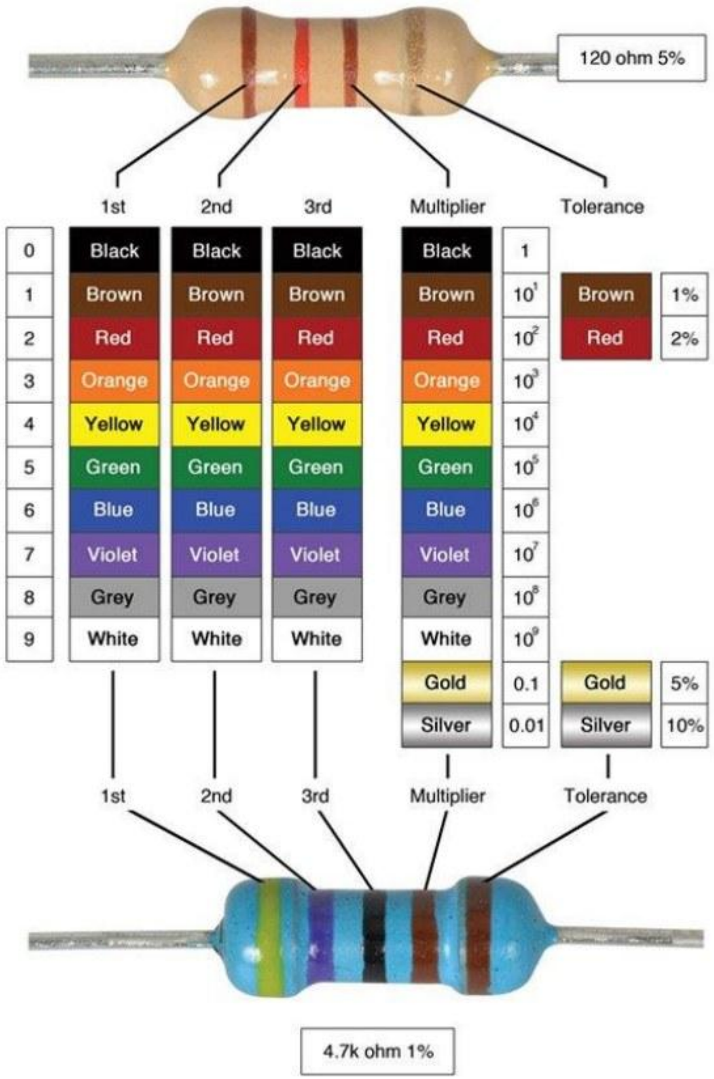
The power associated with a resistor is always positive. Therefore, resistors always absorb power!



Find the power for this resistor.

$$\boxed{p = -vi = -(-Ri)i = Ri^2 > 0!}$$

Resistor


120 ohm 5%
1st
2nd
3rd
Multiplier
Tolerance
0
1
2
3
4
5
6
7
8
9
Black
Brown
Red
Orange
Yellow
Green
Blue
Violet
Grey
White
Gold
Silver
1
10^1
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
0.1
0.01
1%
2%
5%
10%
4.7k ohm 1%

Switch

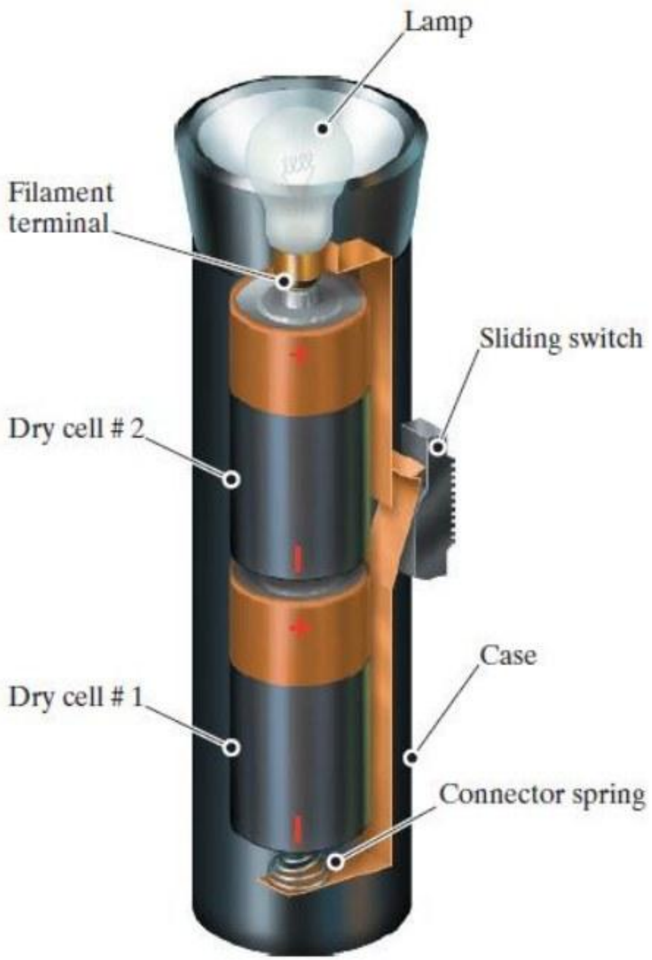


Figure 2.10 ▲ The arrangement of flashlight components.

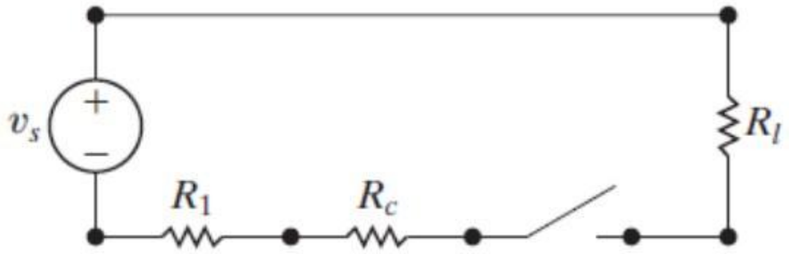
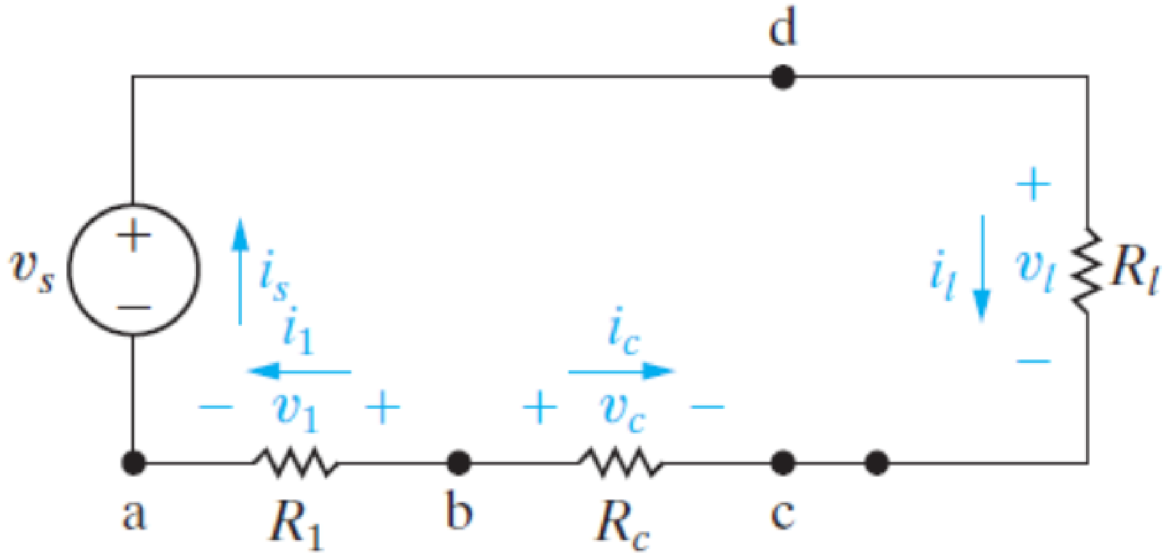


Figure 2.12 ▲ A circuit model for a flashlight.

- **Switch**
  - **<u>Short</u> circuit (R=0)**
  - **<u>Open</u> circuit (R=∞)**

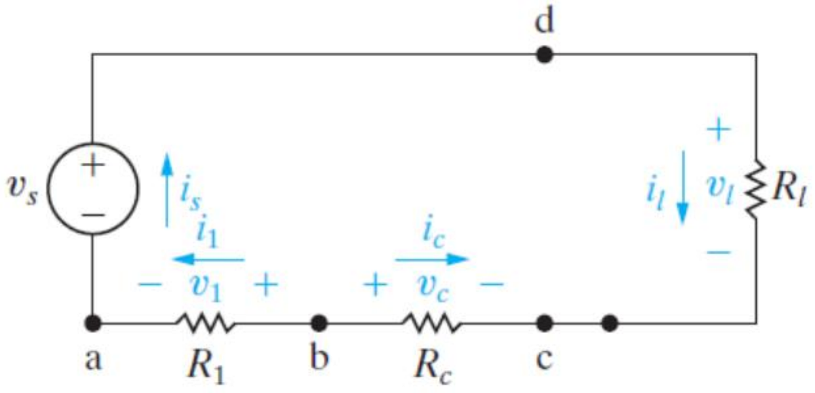
Kirchhoff's Current Law (KCL)

- Consider the circuit shown below. We wish to "solve" this circuit. To solve a circuit, we must find all of the unknown voltages and currents.



- How many unknowns are in this circuit? Seven — 3 unknown voltages and 4 unknown currents → we need 7 independent equations.

Kirchhoff's Current Law (KCL)



- **Ohm's law**

$$v_1 = i_1 R_1,$$

$$v_c = i_c R_c,$$

$$v_l = i_l R_l.$$

KIRCHHOFF'S CURRENT LAW (KCL)

The algebraic sum of all the currents at any node in a circuit equals zero.

Kirchhoff's Current Law (KCL)

- **Apply KCL to the four nodes in the circuit**
  - Convention: Assigning positive (+) sign for current leaving a node

$$
\begin{aligned}
&\text{node a} \qquad i_s - i_1 = 0,\\
&\text{node b} \qquad i_1 + i_c = 0,\\
&\text{node c} \qquad -i_c - i_l = 0,\\
&\text{node d} \qquad i_l - i_s = 0.
\end{aligned}
$$

Note that only 3 of the 4 are independent – the 4th equation can be derived from the other 3.

- In any circuit with ***n*** nodes, ***n-1*** independent equations can be derived from KCL
- We need **one more**, which we can derive from **Kirchhoff's voltage Law**

Kirchhoff's Voltage Law (KVL)

- **Closed path (loop)**
  - a closed path starts at any node, travels through selected circuit elements, and **returns back** to the starting node without including any intermediate nodes more than once.

KIRCHHOFF'S VOLTAGE LAW (KVL)

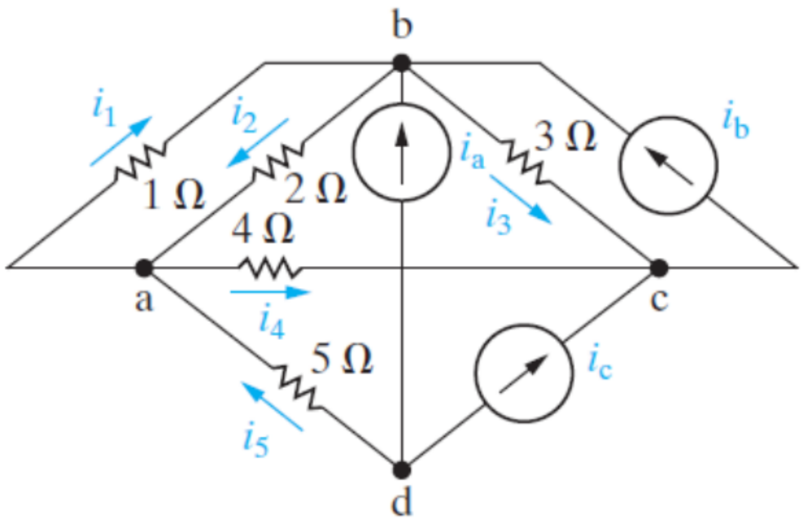
The algebraic sum of all the voltages around any closed path in a circuit equals zero.

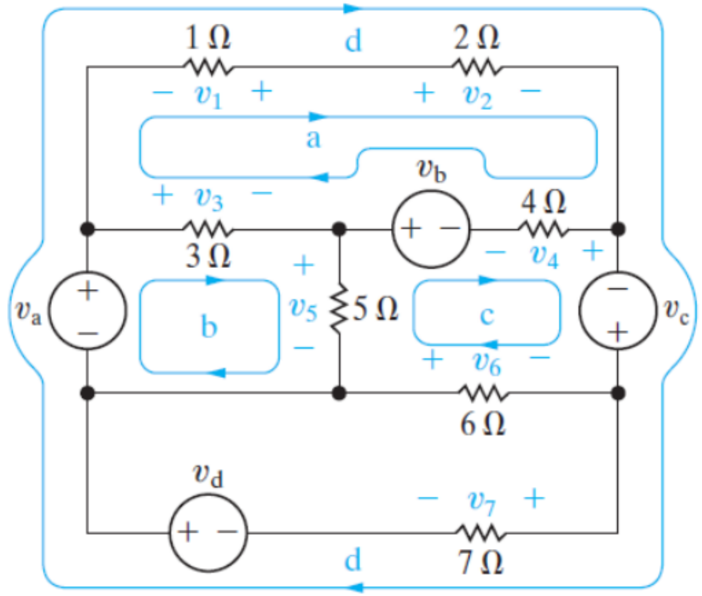
- Here, assuming a positive algebraic sign to voltage drop.

$$v_l - v_c + v_1 - v_s = 0.$$

- Now we have the **seven independent equations**

Kirchhoff's Current & Voltage Law



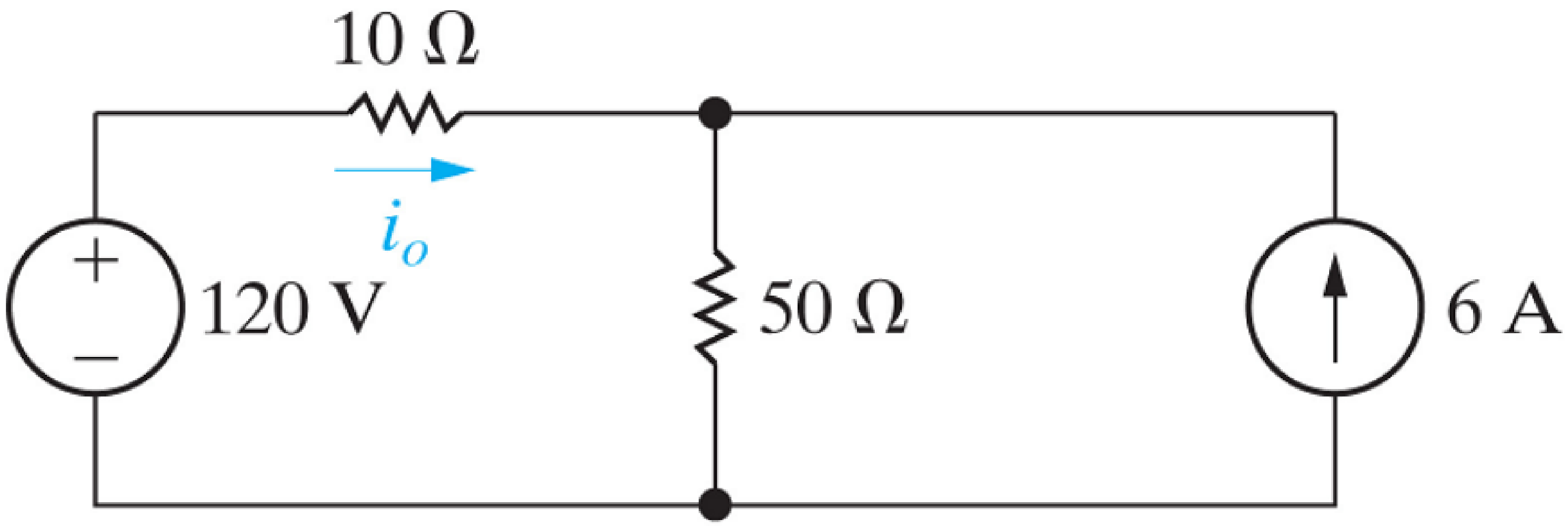


node a	$i_1 + i_4 - i_2 - i_5 = 0,$	path a	$-v_1 + v_2 + v_4 - v_b - v_3 = 0,$
node b	$i_2 + i_3 - i_1 - i_b - i_a = 0,$	path b	$-v_a + v_3 + v_5 = 0,$
node c	$i_b - i_3 - i_4 - i_c = 0,$	path c	$v_b - v_4 - v_c - v_6 - v_5 = 0,$
node d	$i_5 + i_a + i_c = 0.$	path d	$-v_a - v_1 + v_2 - v_c + v_7 - v_d = 0.$

Kirchhoff's Current & Voltage Law

Example 2.8

- Find the current io and show that the power in this circuit balances.



- Begin by labeling all of the unknown voltages and currents and all of the nodes on a copy of this circuit. Figure out how many unknowns you have, then use Ohm’s Law, KCL, and KVL to write the independent equations you need.

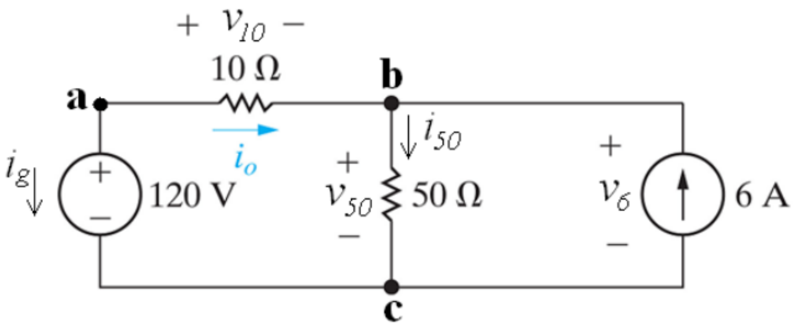
Kirchhoff's Current & Voltage Law

Example 2.8 (continued)

3 unknown voltages and

3 unknown currents

So we need 6 equations



Ohm's Law: $v_{50} = 50 i_{50}$; $\quad v_{10} = 10 i_o$

KCL: $\quad$ At a : $i_g + i_o = 0$; $\quad$ At b : $i_o + 6 = i_{50}$

KVL: $\quad$ left : $-120 + v_{10} + v_{50} = 0$; $\quad$ right : $-v_{50} + v_6 = 0$

Solve KCL at b for i_{50}: $\quad i_{50} = i_o + 6$

Substitute Ohm's Law equations in KVL left:

$$10 i_o + 50 i_{50} = 120$$

Substitute for i_{50} and solve:

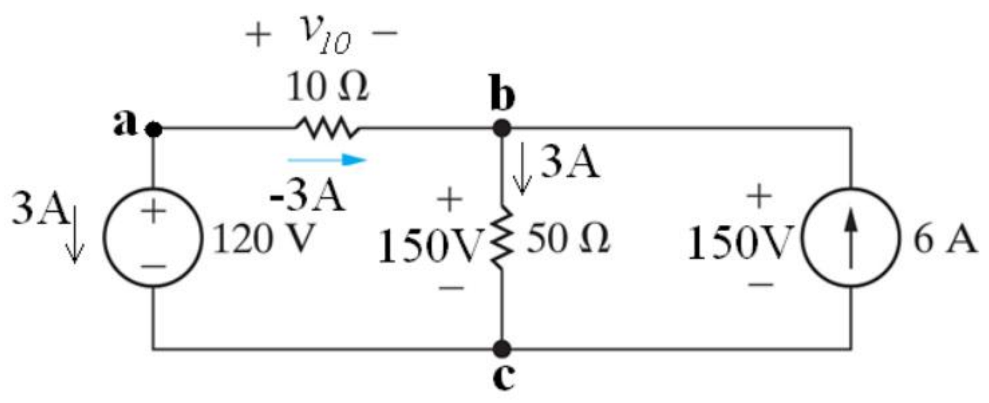
$$10 i_o + 50(i_o + 6) = 120 \quad \Rightarrow \quad 60 i_o = -180$$

$$\Rightarrow \quad i \;= -3 \text{ A}$$

Kirchhoff's Current & Voltage Law

Example 2.8 (continued)

Power balance:



$$p_{50\Omega} = (i_1)^2(50) = (3)^2(50) = 450 \text{ W}.$$

$$p_{10\Omega} = (i_o)^2(10) = (-3)^2(10) = 90 \text{ W}.$$

$$p_{120\text{V}} = -120 i_o = -120(-3) = 360 \text{ W}.$$

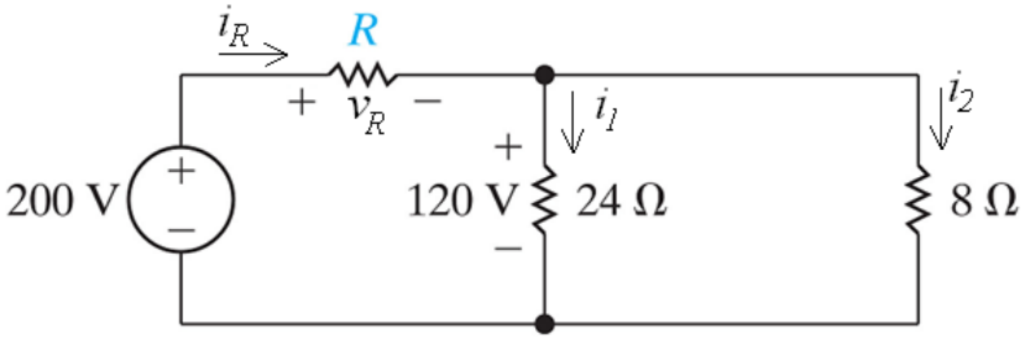
$$p_{6\text{A}} = -v_1(6) = -150(6) = -900 \text{ W}.$$

Total power is 360 + 90 + 450 – 900 = 0 (check!)

Kirchhoff's Current & Voltage Law

AP 2.6

Find R.



To find R we need to find the voltage drop across R and the current through R:

$$\text{KVL left}: -200 + v_R + 120 = 0 \quad \Rightarrow \quad v_R = 200 - 120 = 80\text{ V}$$

$$\text{KCL top}: i_R = i_1 + i_2$$

$$\text{KVL right}: -120 + v_2 = 0 \quad \Rightarrow \quad v_2 = 120\text{ V}$$

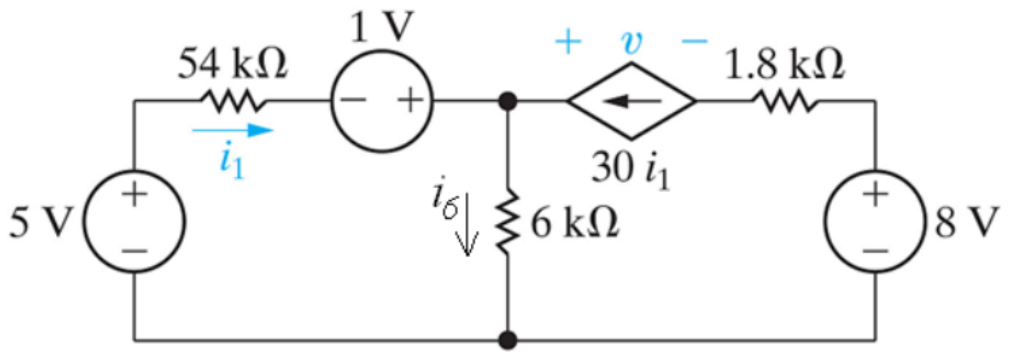
$$\therefore \quad i_R = \frac{120\text{ V}}{24\Omega} + \frac{120\text{ V}}{8\Omega} = 5 + 15 = 20\text{ A}$$

$$\Rightarrow \quad R = \frac{v_R}{i_R} = \frac{80}{20} = 4\Omega$$

Kirchhoff's Current & Voltage Law

AP 2.9

Find i_1, v, and show that the power balances.



$$\text{KVL left}: -5 + 54{,}000 i_1 - 1 + 6000\, i_6 = 0$$

$$\text{KCL top}: i_1 + 30 i_1 = i_6 = 31 i_1$$

$$\Rightarrow \qquad -5 + 54{,}000 i_1 - 1 + 6000\,(31 i_1) = 0$$

$$\Rightarrow \qquad [54{,}000 + (6000)(31)] i_1 = 6 \qquad \therefore \qquad i_1 = 25\,\mu\text{A}$$

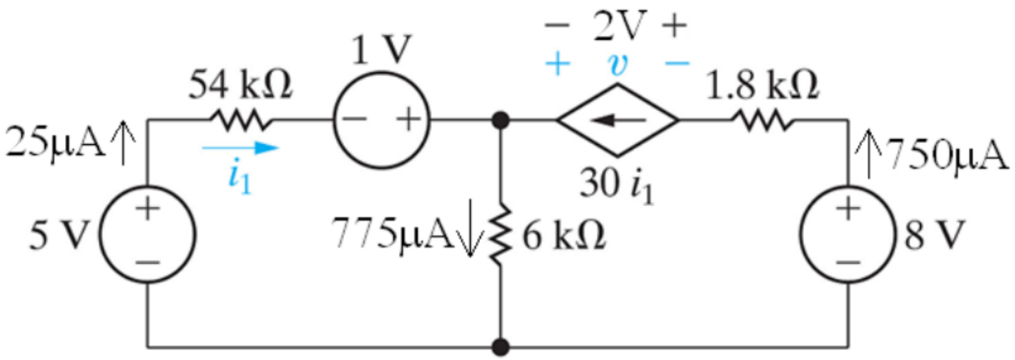
$$\text{KVL right}: -v + (6000)(31 i_1) - 8 + 1800\,(30 i_1) = 0$$

$$\Rightarrow \qquad v = (6000)(31)(25\mu) - 8 + (1800)(30)(25\mu) = -2\ \text{V}$$

Kirchhoff's Current & Voltage Law

AP 2.9 (continued)

Power balance:



$$p_{5V} = -(5)(25\mu) = -120\,\mu W \qquad p_{d.s.} = (2)(750\mu) = 1500\,\mu W$$

$$p_{54k} = (55{,}000)(25\mu)^2 = 33.75\,\mu W \qquad p_{1.8k} = (1800)(750\mu)^2 = 1012.5\,\mu W$$

$$p_{1V} = -(1)(25\mu) = -25\,\mu W \qquad p_{8V} = -(8)(750\mu) = -6000\,\mu W$$

$$p_{6k} = (6000)(775\mu)^2 = 3603.75\,\mu W$$

The sum of the power is

− 120 + 1500 + 33.75 + 1012.5 − 25 − 6000 + 3603.75 = 0!