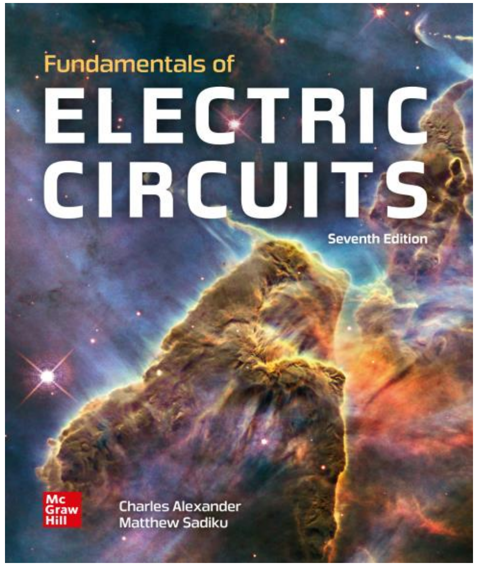
# EHB 211E
# Basics of Electrical Circuits

*Asst. Prof. Onur Kurt*

# Methods of Analysis



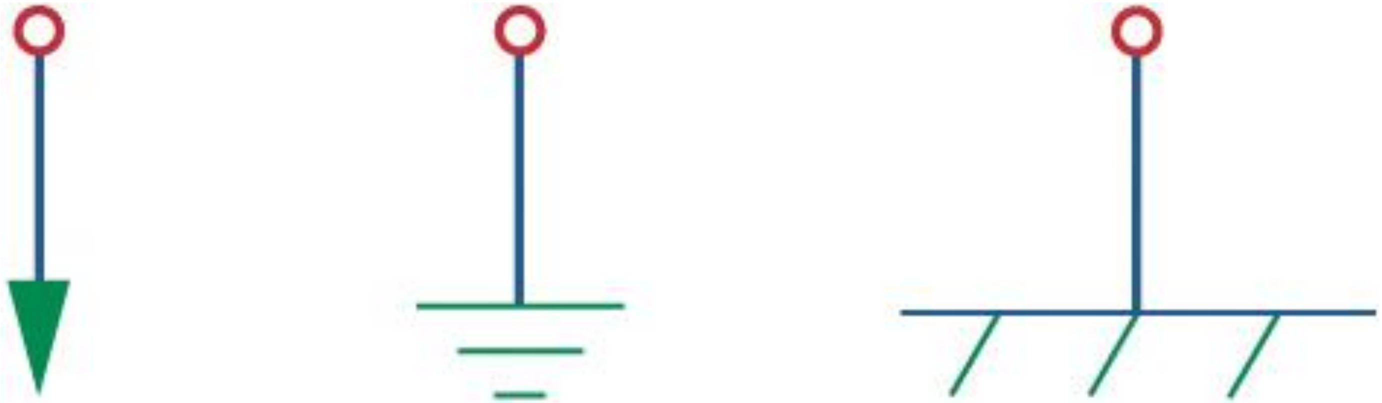

Fundamentals of Electric Circuits by C. Alexander and M. Sadiku, Seventh Edition (McGraw-Hill Education)

# Nodal Analysis

- Provide a general procedure for analyzing circuit using node voltages
- In nodal analysis, determine node voltages
- Steps to determine node voltages:
  - Select a node as the reference node. Assign voltages $v_1, v_2, \ldots, v_{n-1}$ to the remaining n-1 nodes. The voltages are referenced with respect to the reference node.
  - Apply KCL to each of the n-1 nonreference nodes. Use Ohm's law to express the branch currents in terms of node voltages.
  - Solve the resulting simultaneous equations to obtain the unknown node voltages.

# Nodal Analysis

- Choosing a reference (datum) node.
- Reference node: ground node (zero potential)



Common ground

Ground

Mostly used

Chassis ground

# Example 1

- For the circuit shown below, express the branch currents in terms of node voltages.

KCL: $\sum i_{in} = \sum i_{out}$

At node 1: $I_1 = I_2 + i_1 + i_2$

At node 2: $I_2 + i_2 = i_3$

Ohm's law: $v = iR \Rightarrow i = \frac{v}{R}$

Current flows from higher potential (+) to lower potential (-) in a resistor

$$i = \frac{v_{higher} - v_{lower}}{R}$$

$$i_1 = \frac{v_1 - 0}{R_1} \quad \text{or} \quad i_1 = G_1 v_1$$

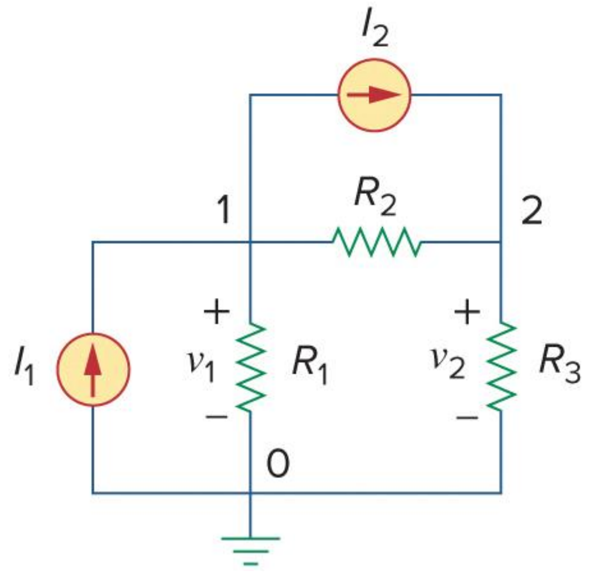
$$G = \frac{1}{R}$$

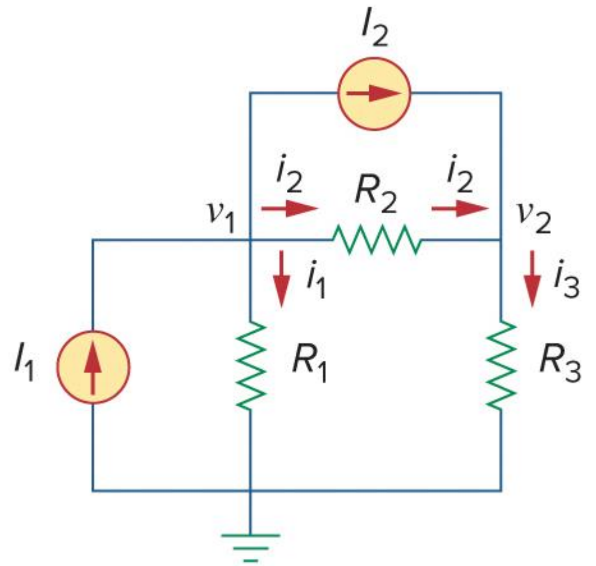
$$i_2 = \frac{v_1 - v_2}{R_2} \quad \text{or} \quad i_2 = G_2(v_1 - v_2)$$

$$i_3 = \frac{v_2 - 0}{R_3} \quad \text{or} \quad i_3 = G_3 v_2$$

$$I_1 = I_2 + \frac{v_1}{R_1} + \frac{v_1 - v_2}{R_2} \quad \text{or} \quad I_1 = I_2 + G_1 v_1 + G_2(v_1 - v_2)$$

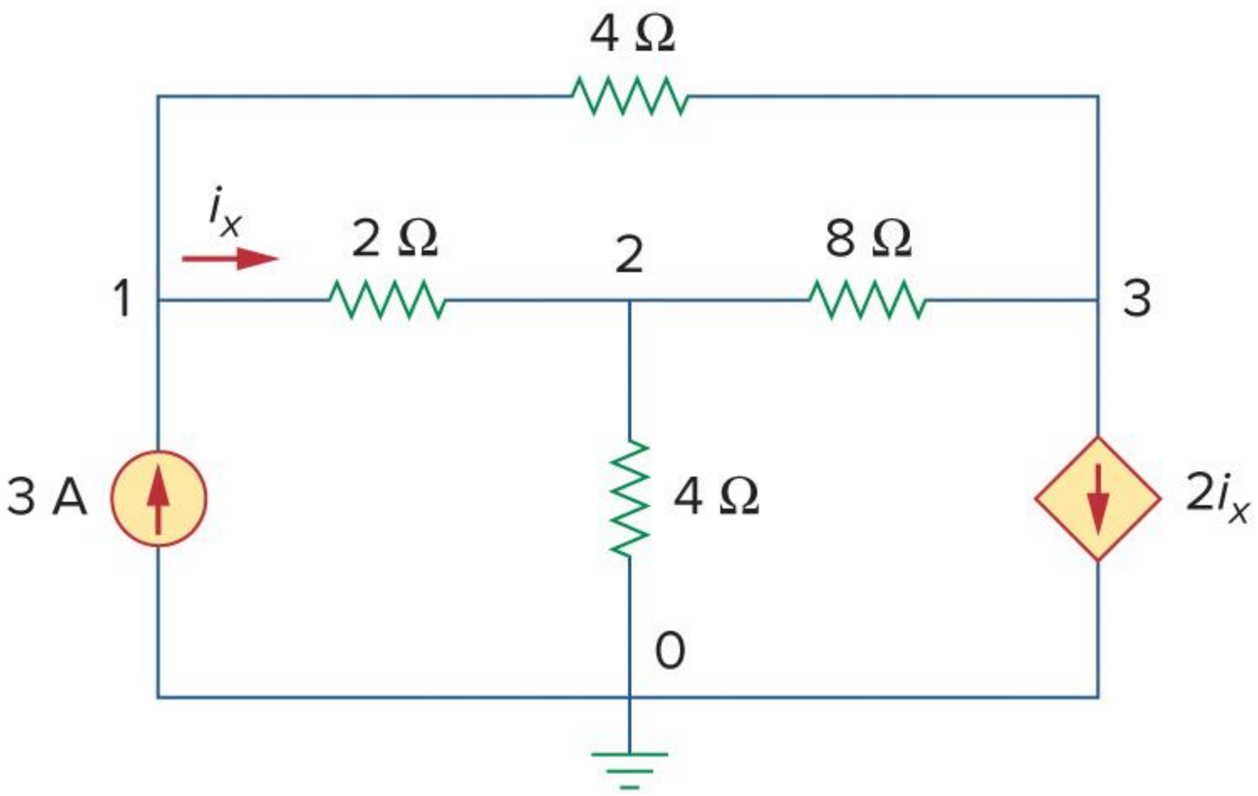
$$I_2 + \frac{v_1 - v_2}{R_2} = \frac{v_2}{R_3} \quad \text{or} \quad I_2 + G_2(v_1 - v_2) = G_3 v_2$$



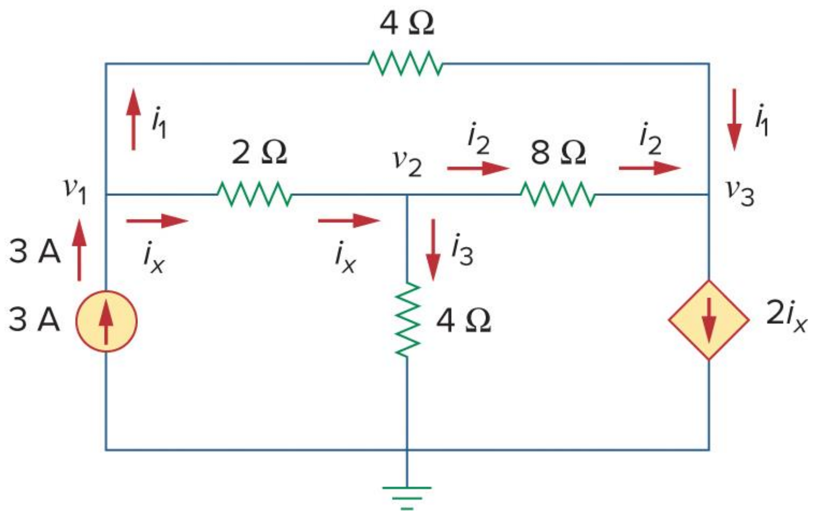



# Example 2

- Determine the voltages at the nodes in the circuit shown below



# Solution




At node 1: $3 = i_1 + i_x$

At node 2: $i_x = i_2 + i_3$

At node 3: $i_1 + i_2 = 2i_x$

$$i_1 = \frac{v_1 - v_3}{4} \qquad i_3 = \frac{v_2}{4}$$

$$i_2 = \frac{v_2 - v_3}{8} \qquad i_x = \frac{v_1 - v_2}{2}$$

$$3 = \frac{v_1 - v_3}{4} + \frac{v_1 - v_2}{2} \Rightarrow 3v_1 - 2v_2 - v_3 = 12 \longrightarrow Eq\ 1$$

$$\frac{v_1 - v_2}{2} = \frac{v_2 - v_3}{8} + \frac{v_2}{4} \Rightarrow 4v_1 - 7v_2 + v_3 = 0 \longrightarrow Eq\ 2$$

$$\frac{v_1 - v_3}{4} + \frac{v_2 - v_3}{8} = 2\left(\frac{v_1 - v_2}{2}\right) \Rightarrow 6v_1 - 9v_2 + 3v_3 = 0 \longrightarrow Eq\ 3$$

3 equation and 3 unknowns $\Rightarrow$

$$v_1 = 4.8\ V$$

$$v_2 = 2.4\ V$$

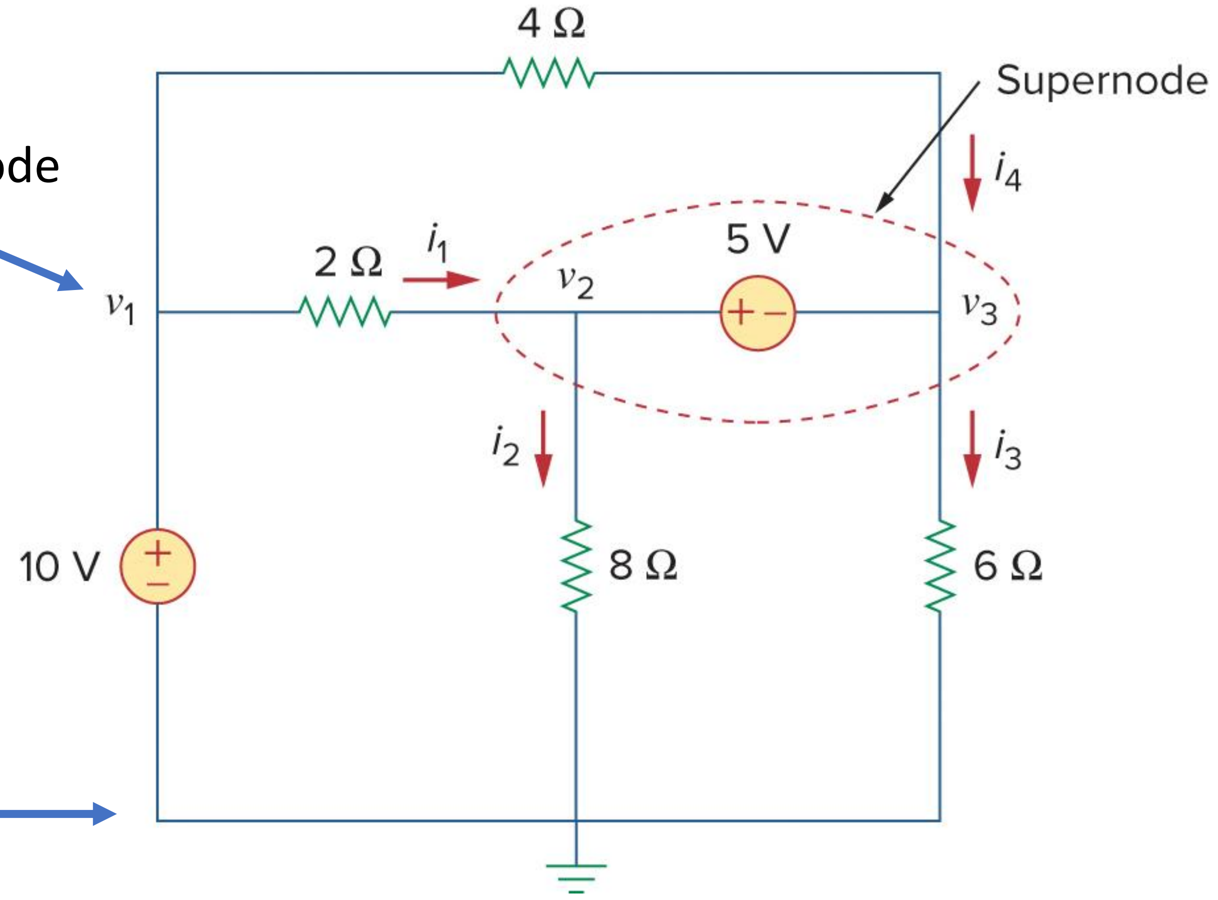
$$v_3 = -2.4\ V$$

# Nodal Analysis with Voltage Sources

- How voltage sources affect nodal analysis. There are two cases.
- Case I: If a voltage source is connected between reference node and nonreference node, set the voltage at nonreference node equal to the voltage of the voltage source.

nonreference node

$$v_1 = 10\text{ V}$$




reference node

# Nodal Analysis with Voltage Sources

- Case II: If the voltage source (dependent or independent) is connected between two nonreference nodes, the two nonreference nodes form a **supernode**.
- Nodes 2 and 3 form a supernode

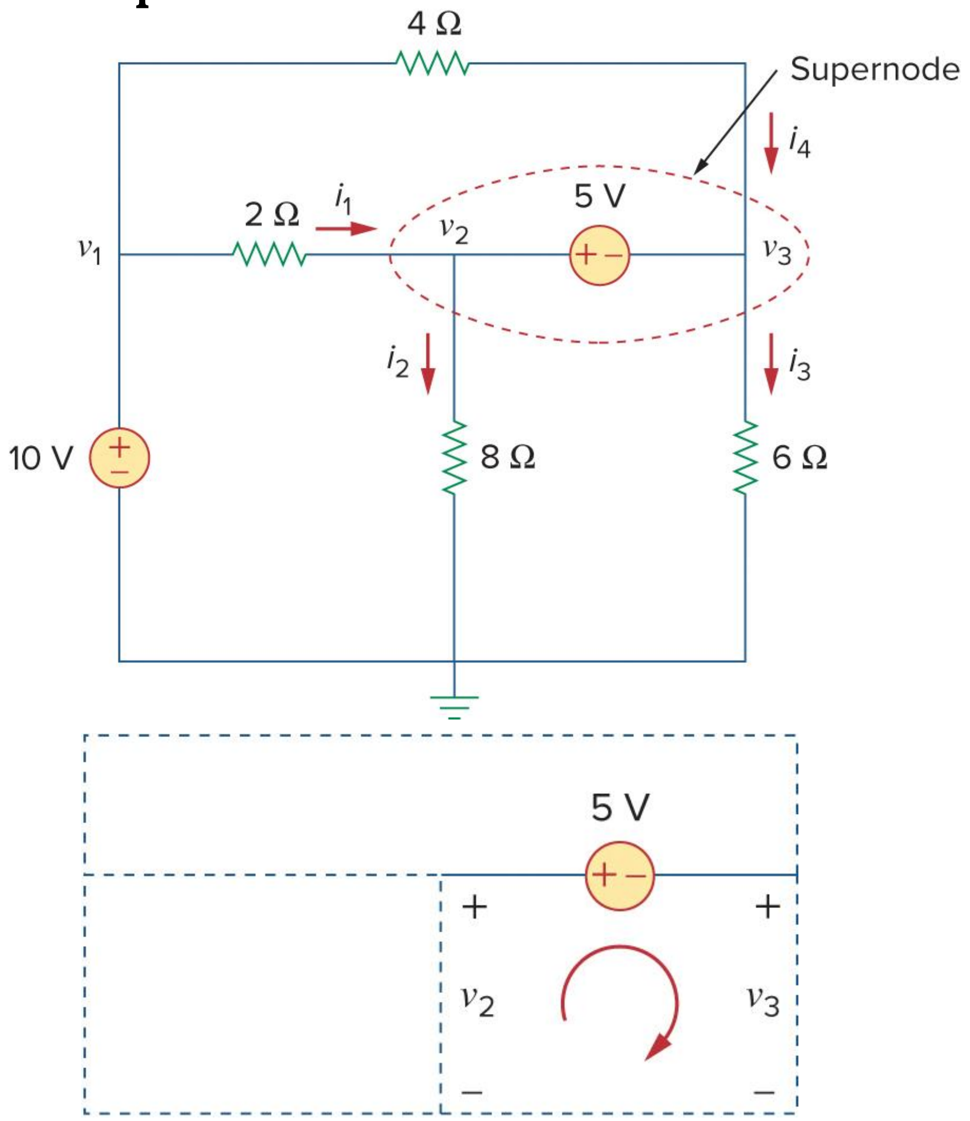
KCL: $\sum i_{in} = \sum i_{out}$

At supernode node: $i_1 + i_4 = i_2 + i_3$

$$i_1 = \frac{v_1 - v_2}{2}, \quad i_2 = \frac{v_2}{8}, \quad i_3 = \frac{v_3}{6}, \quad i_4 = \frac{v_1 - v_3}{4}$$

$$\frac{v_1 - v_2}{2} + \frac{v_1 - v_3}{4} = \frac{v_2}{8} + \frac{v_3}{6} \qquad \text{where } v_1 = 10\text{ V}$$

KVL: $\sum_{m=1}^{M} V_m = 0, \quad -v_2 + 5 + v_3 = 0 \Rightarrow v_2 - v_3 = 5$

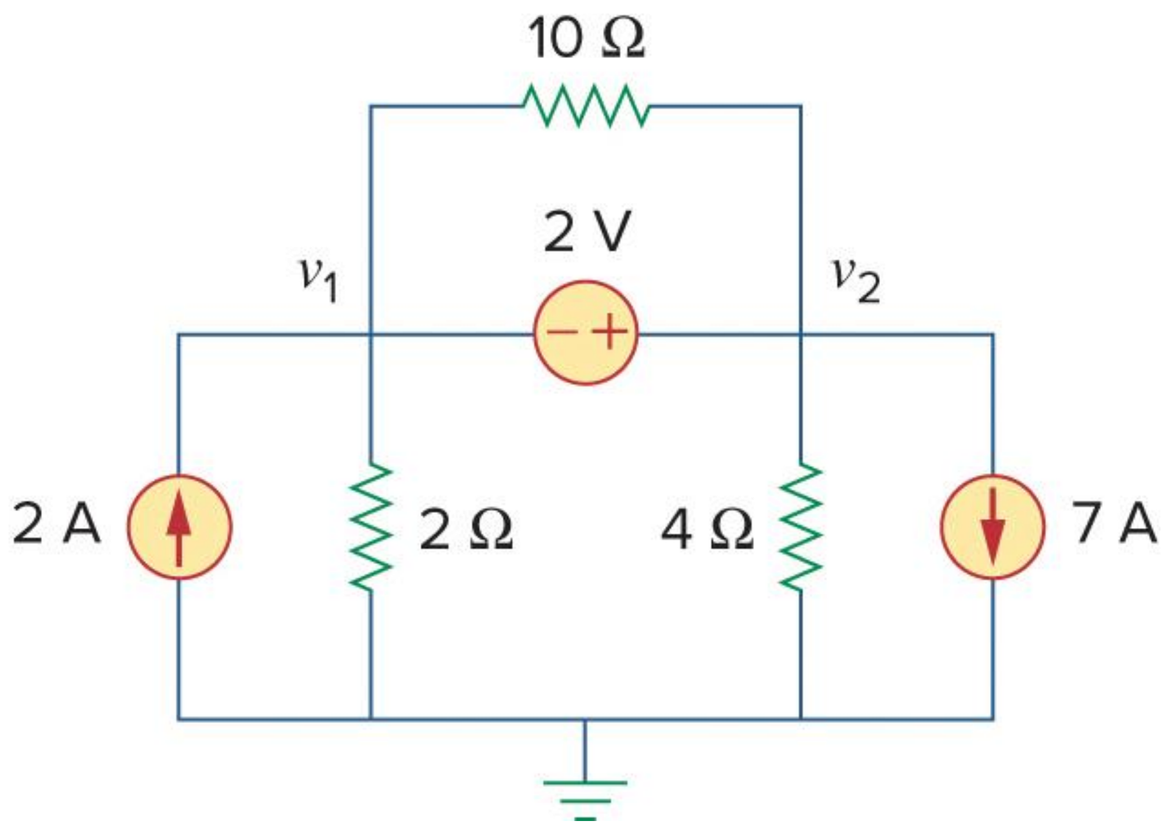



KCL must be satisfied at the supernode. KCL not only applies to node but also closed surface

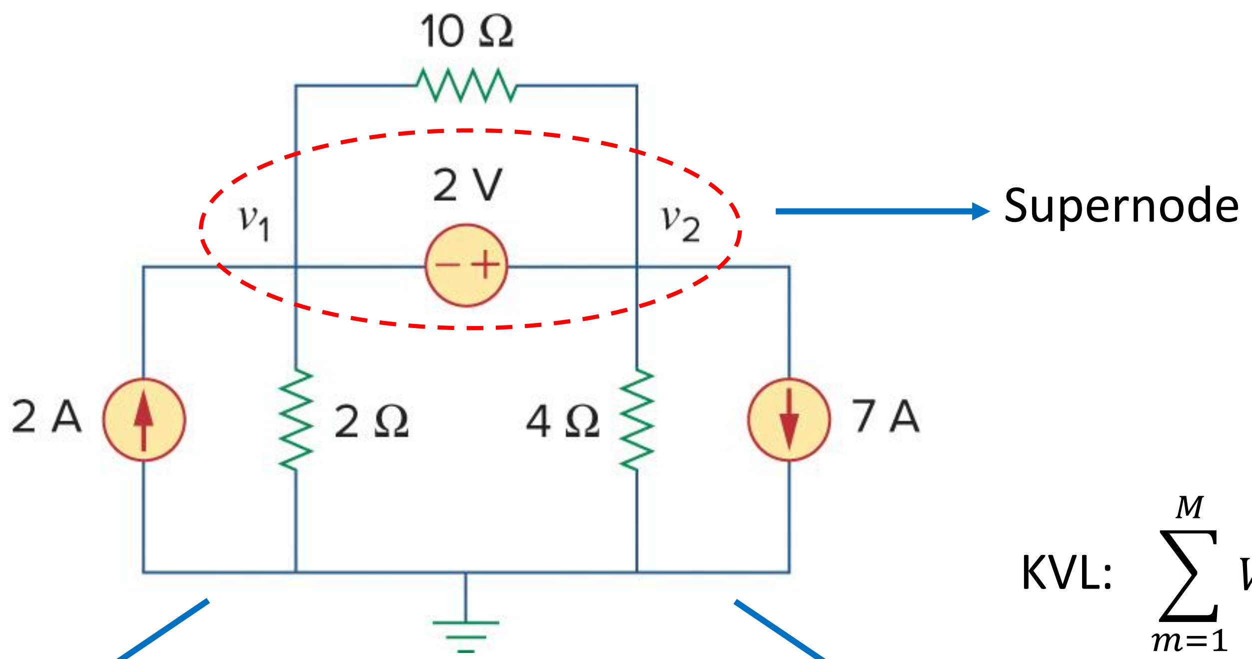
Supernode requires the application of both KCL and KVL

# Example 3

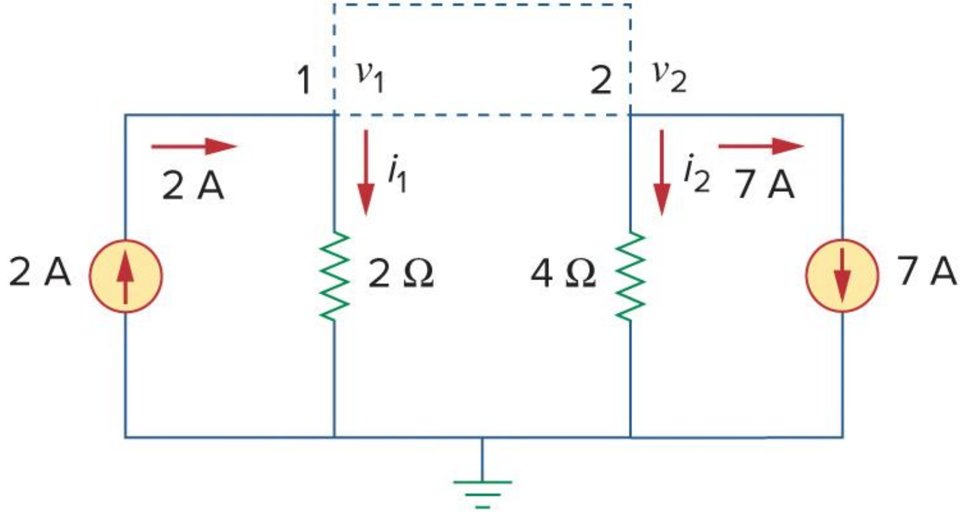
- For the circuit shown below, find the node voltages.



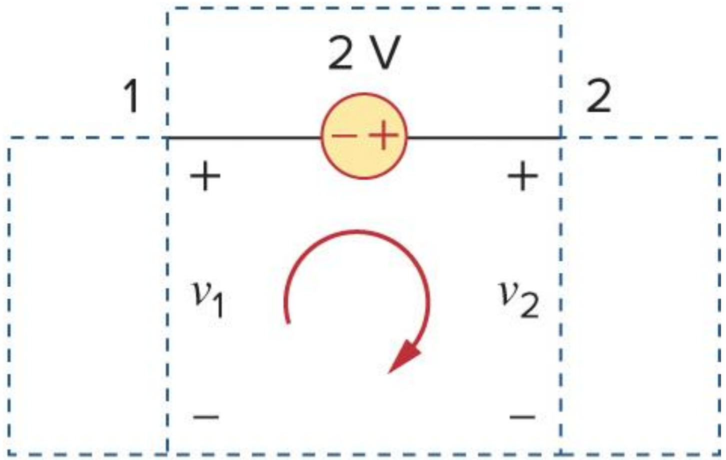
# Solution




KCL: $\sum i_{in} = \sum i_{out}$




KVL: $\sum_{m=1}^{M} V_m = 0,$



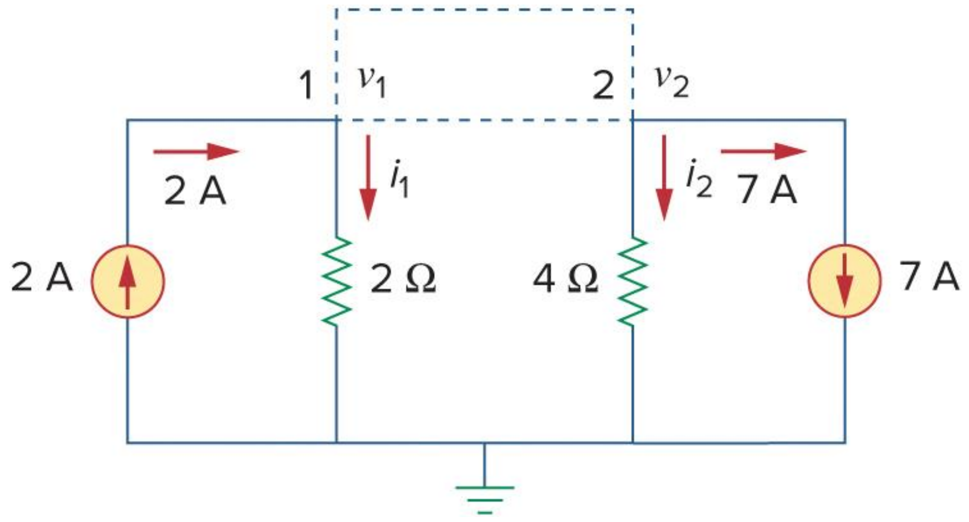
# Solution

Apply KCL at supernode:

$$2 = i_1 + i_2 + 7 \Rightarrow i_1 + i_2 = -5$$

$$\left. i_1 = \frac{v_1}{2},\quad i_2 = \frac{v_2}{4} \right\} \quad \frac{v_1}{2} + \frac{v_2}{4} = -5$$

$$\frac{v_1}{2} + \frac{v_2}{4} = -5 \Rightarrow 2v_1 + v_2 = -20 \longrightarrow Eq\ 1$$

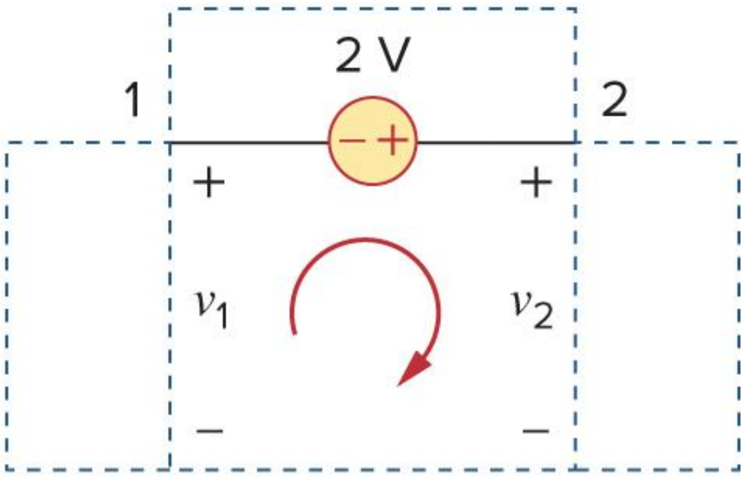



Apply KVL at supernode:

$$-v_1 - 2 + v_2 = 0 \Rightarrow -v_1 + v_2 = 2 \longrightarrow Eq\ 2$$

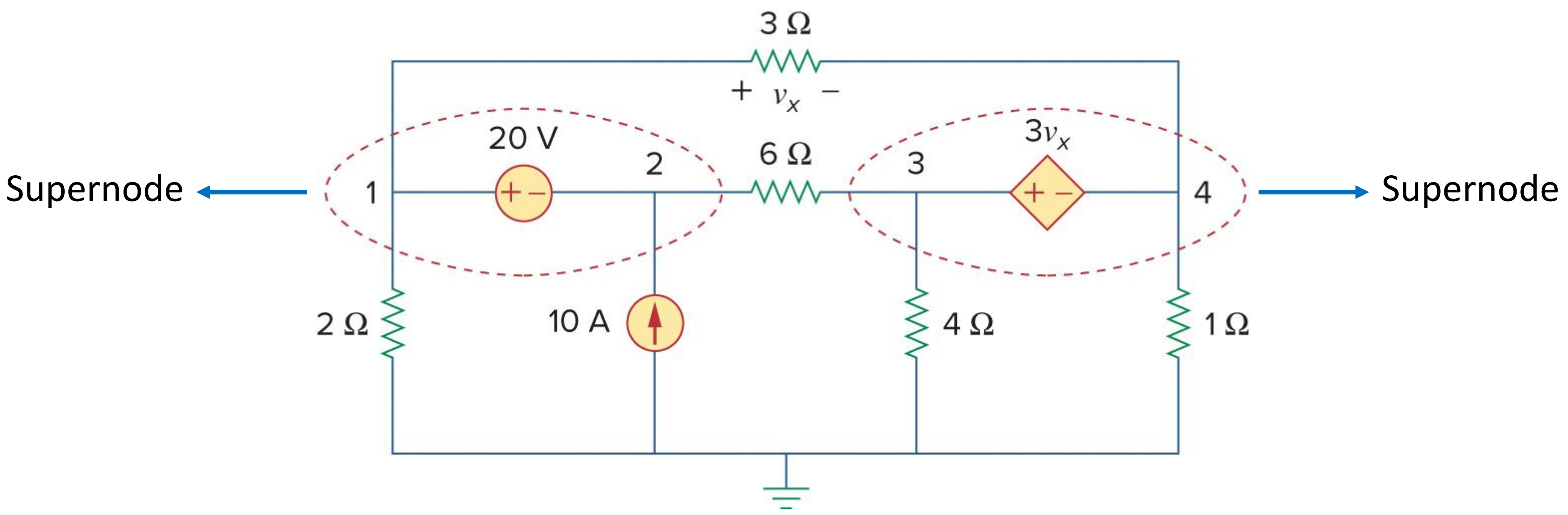
$2\ eqs\ and\ 2\ unknows$:

$$\left. \begin{aligned} 2v_1 + v_2 &= -20 \\ -v_1 + v_2 &= 2 \end{aligned} \right\} \quad \begin{aligned} v_1 &= -7.333\ V \\ v_2 &= -5.333\ V \end{aligned}$$



# Example 4

- Find the node voltages in the circuit shown below



# Solution

- Node 1 and 2 as well as node 3 and 4 form a supernode:

Apply KCL at supernode 1 and 2:

$$i_3 + 10 = i_1 + i_2$$

$$\frac{v_3 - v_2}{6} + 10 = \frac{v_1 - v_4}{3} + \frac{v_1}{2}$$

or

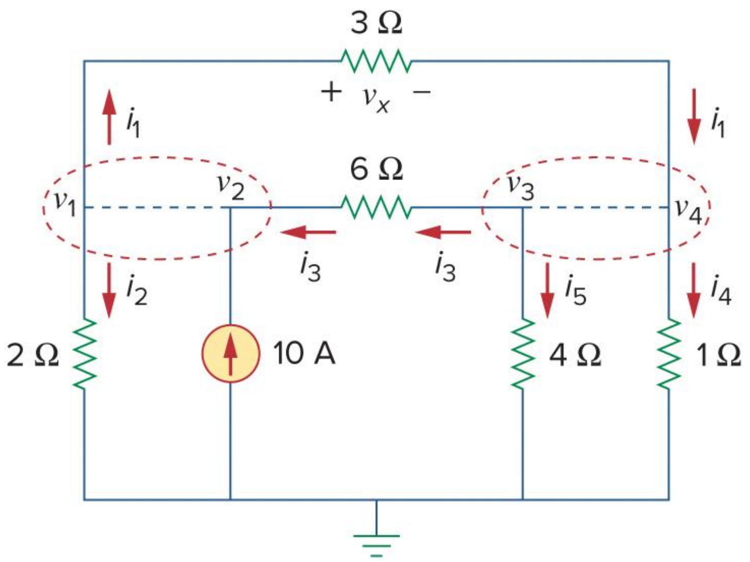
$$5v_1 + v_2 - v_3 - 2v_4 = 60$$

Apply KCL at supernode 3 and 4:

$$i_1 = i_3 + i_4 + i_5 \qquad \Rightarrow \qquad \frac{v_1 - v_4}{3} = \frac{v_3 - v_2}{6} + \frac{v_4}{1} + \frac{v_3}{4}$$

or

$$4v_1 + 2v_2 - 5v_3 - 16v_4 = 0$$



# Solution

Apply KVL at loop 1:

$$-v_1 + 20 + v_2 = 0 \qquad \Rightarrow \qquad v_1 - v_2 = 20$$

Apply KVL at loop 2:

$$-v_3 + 3v_x + v_4 = 0 \qquad\qquad v_x = v_1 - v_4$$

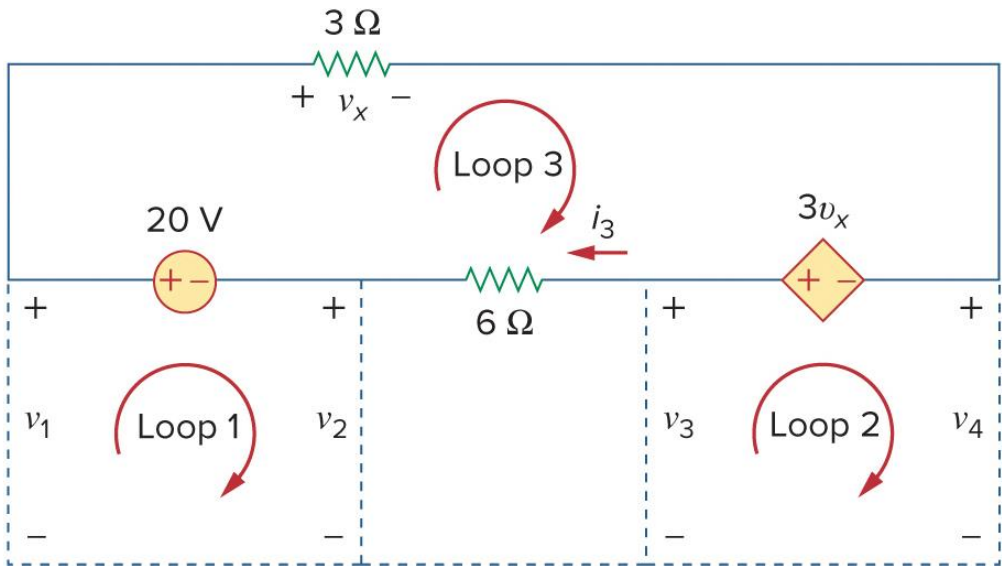
$$3v_1 - v_3 - 2v_4 = 0$$

Apply KVL at loop 3:

$$v_x - 3v_x + 6i_3 - 20 = 0$$

$$6i_3 = v_3 - v_2 \text{ and } v_x = v_1 - v_4$$

$$-2v_1 - v_2 + v_3 + 2v_4 = 20$$




5 *eqs and* 4 *unknows*:

$$\left.\begin{aligned} 5v_1 + v_2 - v_3 - 2v_4 &= 60 \\ 4v_1 + 2v_2 - 5v_3 - 16v_4 &= 0 \end{aligned}\right\} \text{KCL}$$

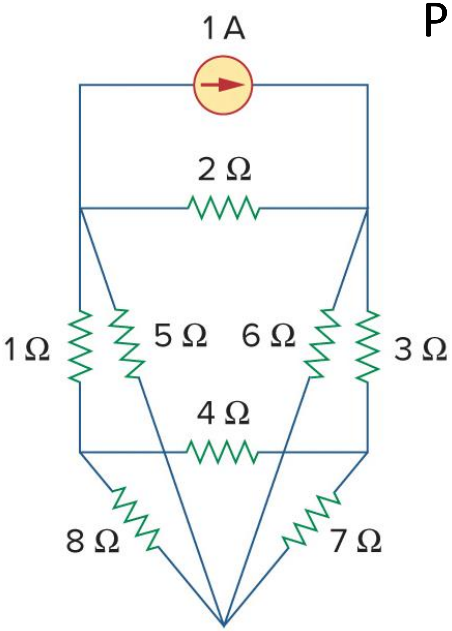
$$\left.\begin{aligned} v_1 - v_2 &= 20 \\ 3v_1 - v_3 - 2v_4 &= 0 \\ -2v_1 - v_2 + v_3 + 2v_4 &= 20 \end{aligned}\right\} \text{KVL}$$

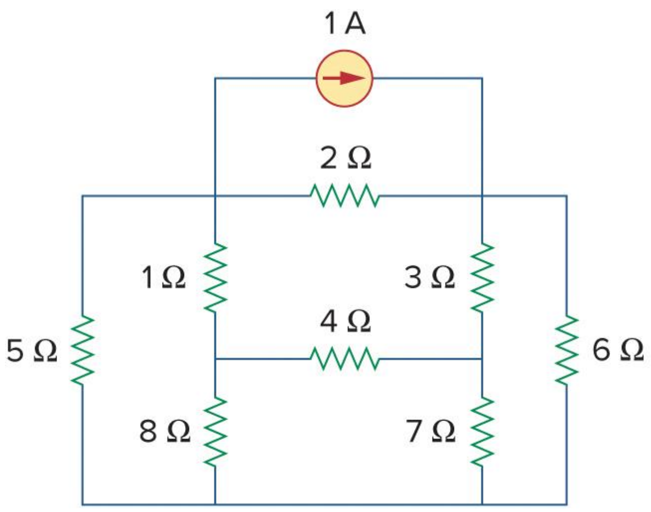
$$v_1 = 26.67 \text{ V}$$
$$v_2 = 6.667 \text{ V}$$
$$v_3 = 173.33 \text{ V}$$
$$v_4 = -46.67 \text{ V}$$

# Mesh Analysis

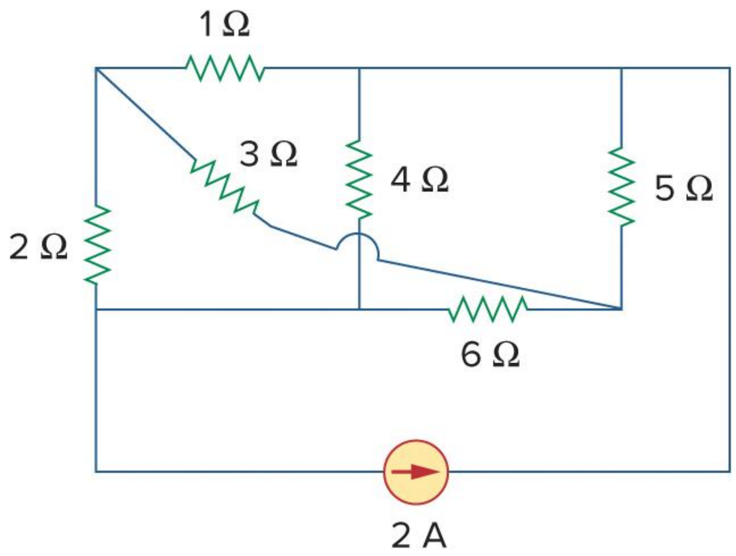
- Provide a procedure for analyzing circuit using mesh currents
- Mesh analysis is also known as loop analysis or the mesh-current method
- In mesh analysis, apply KVL to find unknown currents
- Mesh analysis can only be applied to a planar circuit.
- Planar circuit: drawn in a plane with no branches crossing one another. Otherwise it nonplanar.

Planar Circuit




Nonplanar Circuit

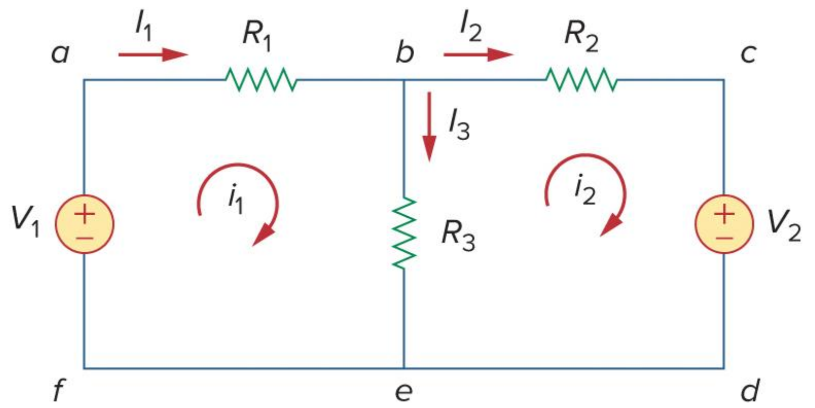



Nodal analysis applies KCL to find unknows voltages (For supernode: apply both KCL & KVL)
Mesh analysis applies KVL to find unknown currents (For supermesh: apply both KVL & KCL)

# Mesh Analysis

- What is a mesh?
  - A loop which does not contain any other loops within it.
  - Path abefa: mesh (only one loop)
  - Path bcdeb: mesh (only one loop)
  - Path abcdefa: not a mesh (two loops)
- The current through a mesh is known as mesh current
- Steps to determine mesh current:
  - Assign a mesh current $i_1, i_2, \ldots, i_n$ to the n meshes.
  - Apply KVL to each of the n meshes. Use Ohm's law to express the voltages in terms of the mesh current
  - Solve the resulting n simultaneous equations to get the mesh currents

$i_1$ and $i_2$: mesh currents
$I_1$ , $I_2$, and $I_3$: branch currents



# Example 5

- Obtain branch currents using mesh analysis

- $1^{st}$: assign mesh currents ($i_1$ and $i_2$) to meshes 1 and 2
- Direction of mesh currents is chosen arbitrarily (clockwise)

- $2^{nd}$: apply KVL to mesh 1:

$$-V_1 + R_1 i_1 + R_3(i_1 - i_2) = 0$$

$$(R_1 + R_3)i_1 - R_3 i_2 = V_1 \longrightarrow Eq\ 1$$

- Apply KVL to mesh 2:

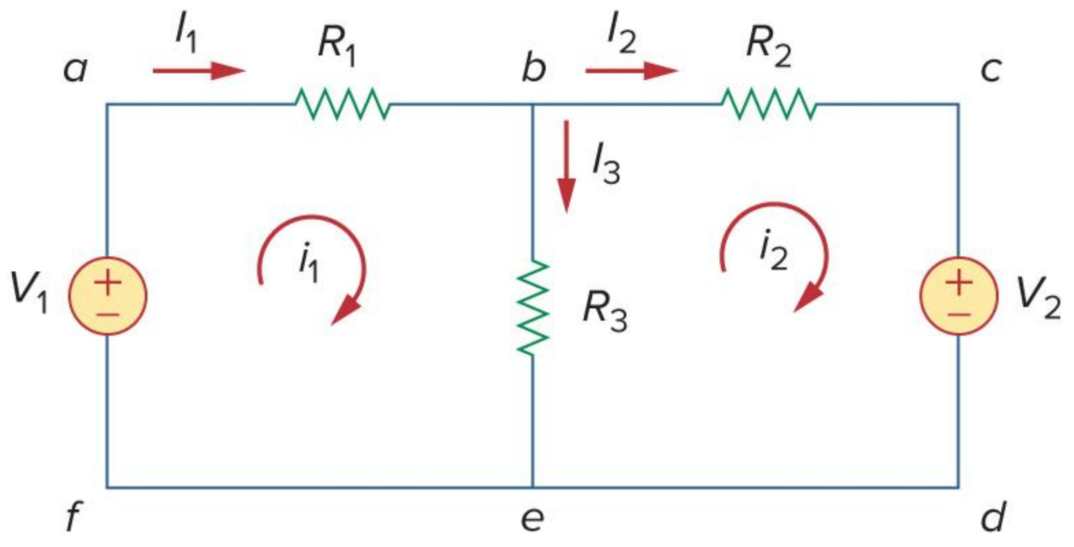
$$R_2 i_2 + V_2 + R_3(i_2 - i_1) = 0$$

$$-R_3 i_1 + (R_2 + R_3)i_2 = -V_2 \longrightarrow Eq\ 2$$

- Last step is to solve for the mesh currents:

Equations in matrix form:

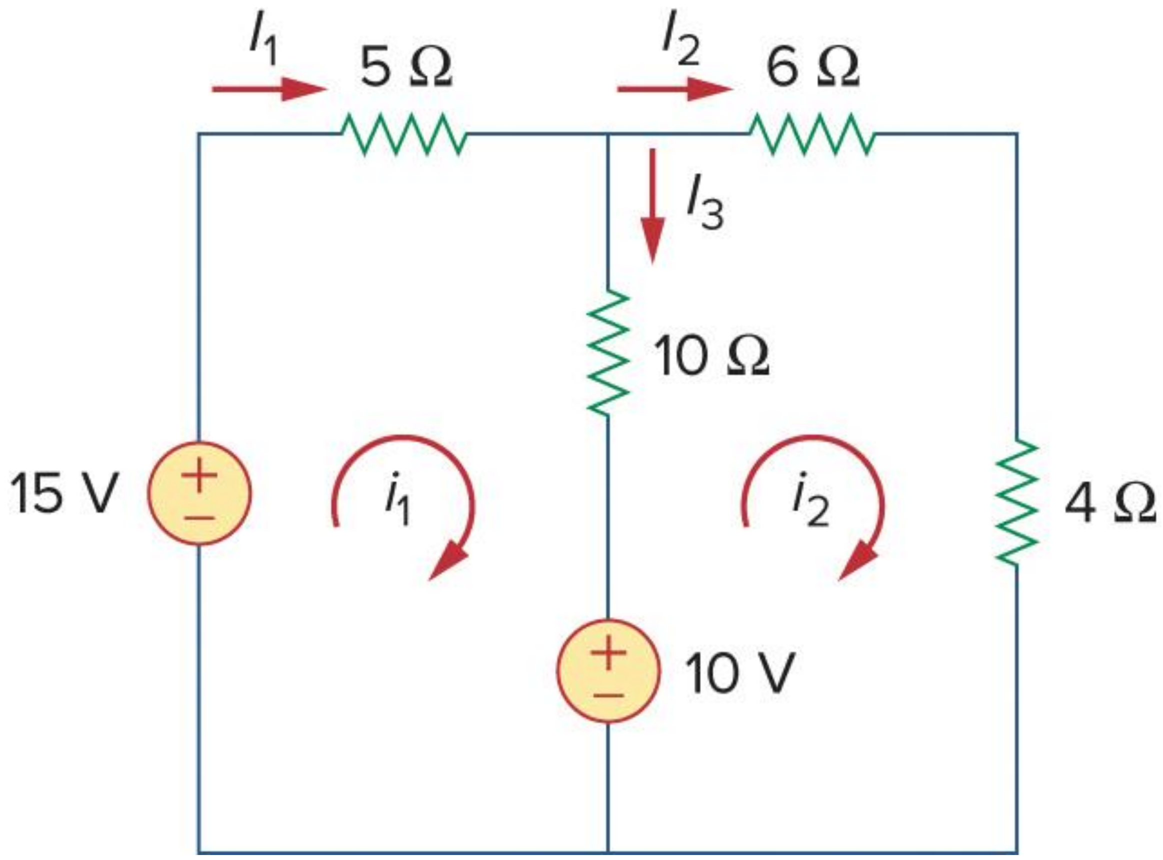
$$\begin{bmatrix} R_1 + R_3 & -R_3 \\ -R_3 & R_2 + R_3 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} V_1 \\ -V_2 \end{bmatrix}$$




$$I_1 = i_1, \qquad I_2 = i_2, \qquad I_3 = i_1 - i_2$$

# Example 6

- For the circuit shown below, find the branch currents using mesh analysis.



# Solution

- 1st: assign mesh currents
- 2nd: apply KVL to mesh 1:

$$-15 + 5i_1 + 10(i_1 - i_2) + 10 = 0$$

$$3i_1 - 2i_2 = 1 \longrightarrow Eq\ 1$$

- Apply KVL to mesh 2:

$$6i_2 + 4i_2 + 10(i_2 - i_1) - 10 = 0$$

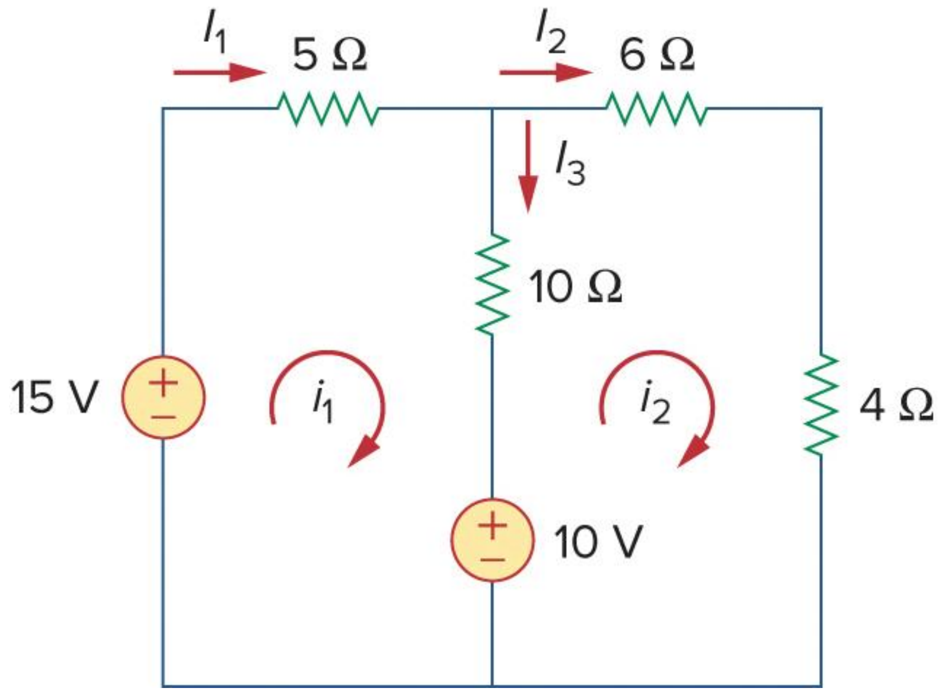
$$i_1 = 2i_2 - 1 \longrightarrow Eq\ 2$$

- Substitute $Eq$ 2 into $Eq$ 1:

$$6i_2 - 3 - 2i_2 = 1 \qquad \Rightarrow \qquad i_2 = 1\text{ A}$$

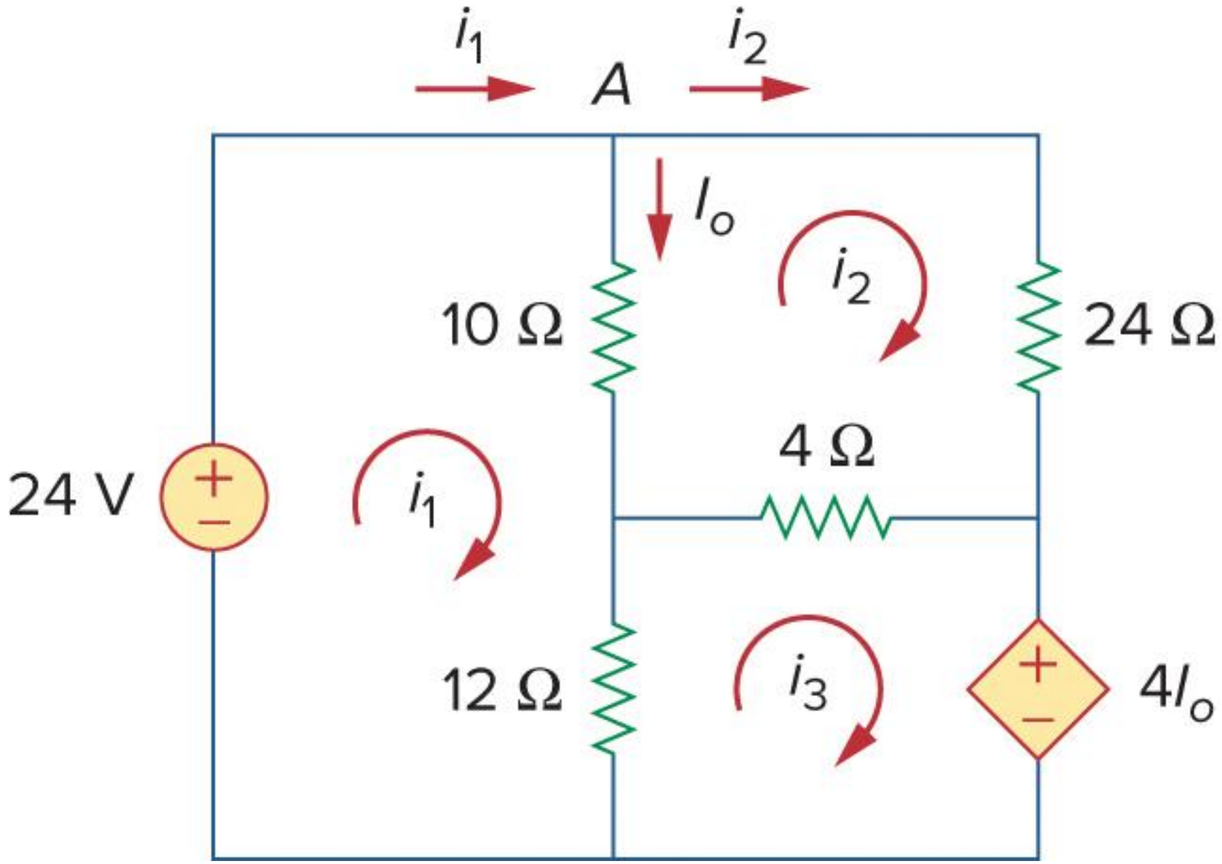
$$i_1 = 2i_2 - 1 = 2 - 1 = 1\text{ A}$$

$$I_1 = i_1 = 1\text{ A}, \qquad I_2 = i_2 = 1\text{ A}, \qquad I_3 = i_1 - i_2 = 0$$



# Example 7

- Use mesh analysis to find the current $I_0$ in the circuit shown below



# Solution

- Apply KVL to three meshes
- For mesh 1:

$$-24 + 10(i_1 - i_2) + 12(i_1 - i_3) = 0$$

$$11i_1 - 5i_2 - 6i_3 = 12 \longrightarrow Eq\ 1$$

- For mesh 2:

$$24i_2 + 4(i_2 - i_3) + 10(i_2 - i_1) = 0$$

$$-5i_1 + 19i_2 - 2i_3 = 0 \longrightarrow Eq\ 2$$

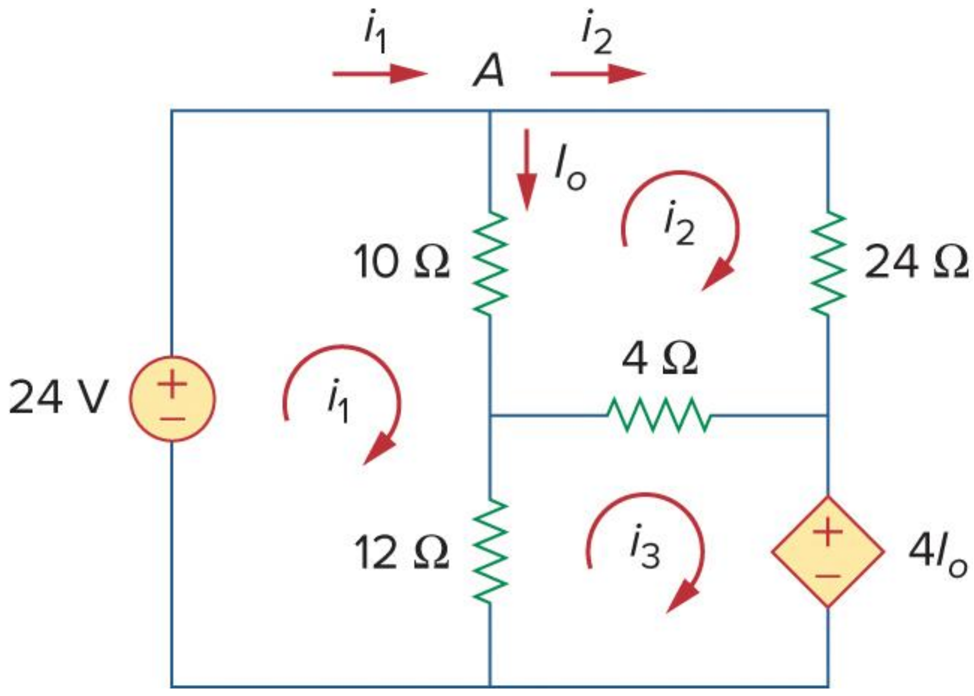
- For mesh 3:

$$4I_o + 12(i_3 - i_1) + 4(i_3 - i_2) = 0$$

- At node A, KCL: $I_o = i_1 - i_2$

$$4(i_1 - i_2) + 12(i_3 - i_1) + 4(i_3 - i_2) = 0$$

$$-i_1 - i_2 + 2i_3 = 0 \longrightarrow Eq\ 3$$




Equations in matrix form:

$$\begin{bmatrix} 11 & -5 & -6 \\ -5 & 19 & -2 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} 12 \\ 0 \\ 0 \end{bmatrix}$$

# Solution

- Cramer's rule

$$i_1 = \frac{\Delta_1}{\Delta} \qquad i_2 = \frac{\Delta_2}{\Delta} \qquad i_3 = \frac{\Delta_3}{\Delta}$$

where Δ is determinant

$$\begin{bmatrix} 11 & -5 & -6 \\ -5 & 19 & -2 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} 12 \\ 0 \\ 0 \end{bmatrix}$$

$$\Delta = \begin{array}{r|rrr|l} & 11 & -5 & -6 & \\ & -5 & 19 & -2 & \\ & -1 & -1 & 2 & \\ - & 11 & -5 & -6 & + \\ - & -5 & 19 & -2 & + \\ - & & & & + \end{array}$$

$$= 418 - 30 - 10 - 114 - 22 - 50 = 192$$

$$\Delta_1 = \begin{array}{r|rrr|l} & 12 & -5 & -6 & \\ & 0 & 19 & -2 & \\ & 0 & -1 & 2 & \\ - & 12 & -5 & -6 & + \\ - & 0 & 19 & -2 & + \\ - & & & & + \end{array} = 456 - 24 = 432$$

$$\Delta_2 = \begin{array}{r|rrr|l} & 11 & 12 & -6 & \\ & -5 & 0 & -2 & \\ & -1 & 0 & 2 & \\ - & 11 & 12 & -6 & + \\ - & -5 & 0 & -2 & + \\ - & & & & + \end{array} = 24 + 120 = 144$$

$$\Delta_3 = \begin{array}{r|rrr|l} & 11 & -5 & 12 & \\ & -5 & 19 & 0 & \\ & -1 & -1 & 0 & \\ - & 11 & -5 & 12 & + \\ - & -5 & 19 & 0 & + \\ - & & & & + \end{array} = 60 + 228 = 288$$

# Solution

$$i_1 = \frac{\Delta_1}{\Delta} = \frac{432}{192} = 2.25 \text{ A}, \qquad i_2 = \frac{\Delta_2}{\Delta} = \frac{144}{192} = 0.75 \text{ A},$$

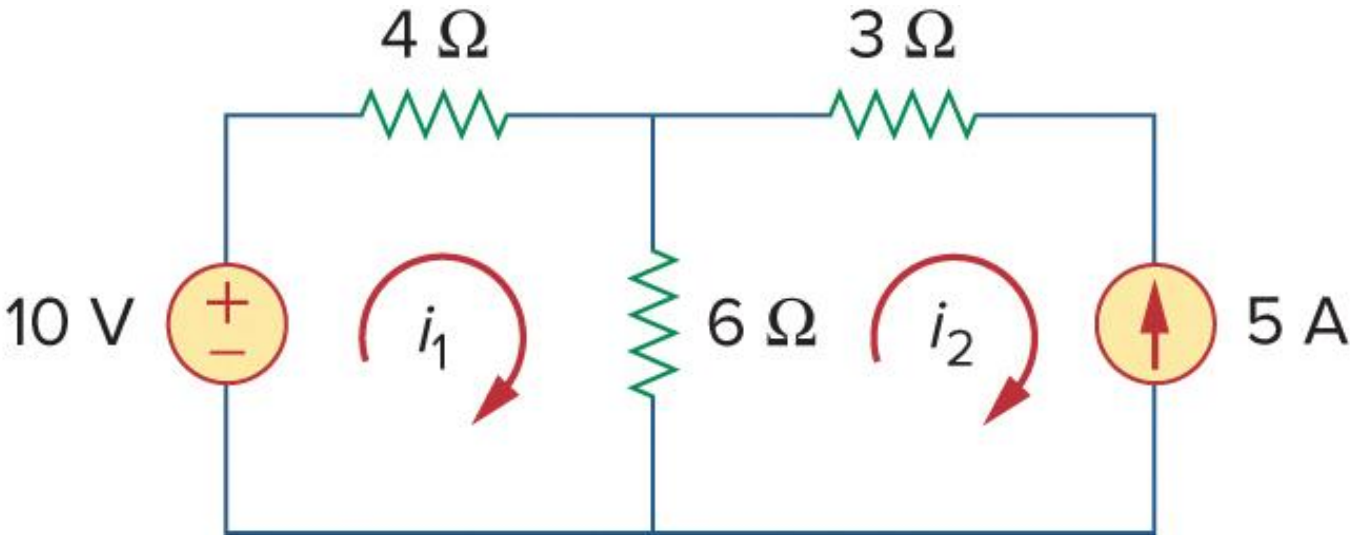
$$i_3 = \frac{\Delta_3}{\Delta} = \frac{288}{192} = 1.5 \text{ A}$$

$$I_o = i_1 - i_2 = 1.5 \text{ A}.$$

# Mesh Analysis with Current Sources

- How current sources affect mesh analysis. There are two cases.
- Case I: when a current source exists only in one mesh

- Set $i_2 = -5\ \mathrm{A}$
- Write mesh equation for the other mesh




KVL for mesh 1:

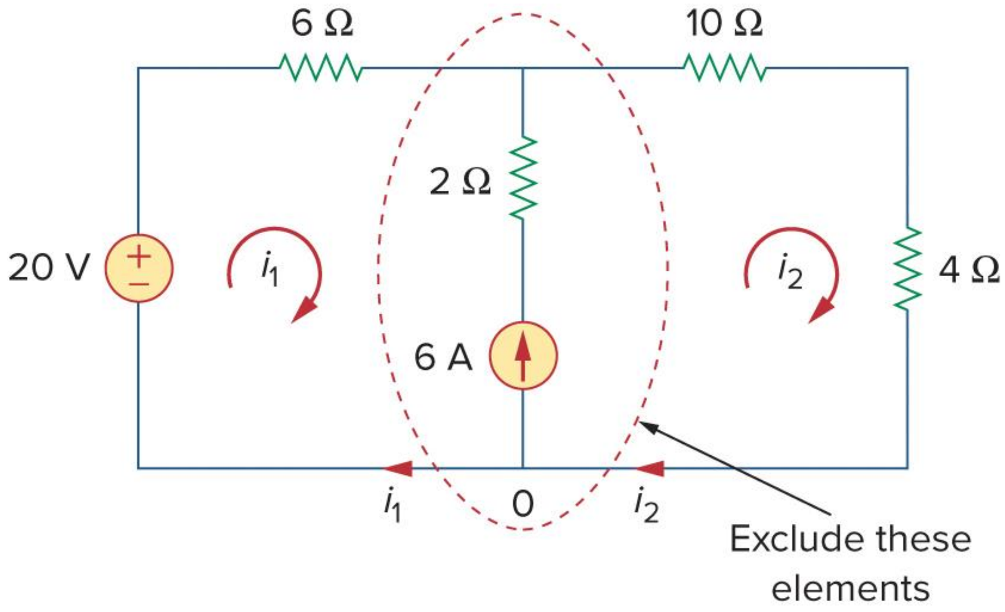
$$-10 + 4i_1 + 6(i_1 - i_2) = 0$$

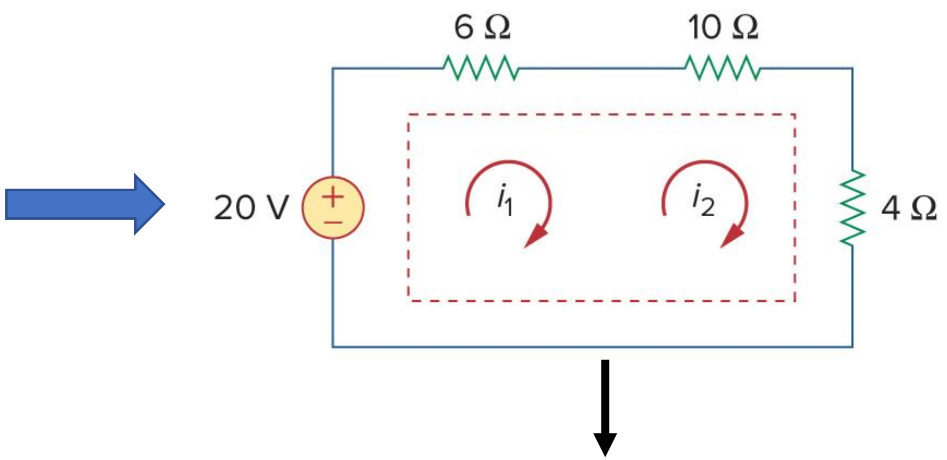
$$-10 + 4i_1 + 6i_1 - 6i_2 = 0$$

$$10i_1 - 6i_2 = 10 \Rightarrow i_1 = -2\ A$$

# Mesh Analysis with Current Sources

- Case II: When a current source exists between two meshes, create a **supermesh** by excluding the current source and any elements connected in series with it



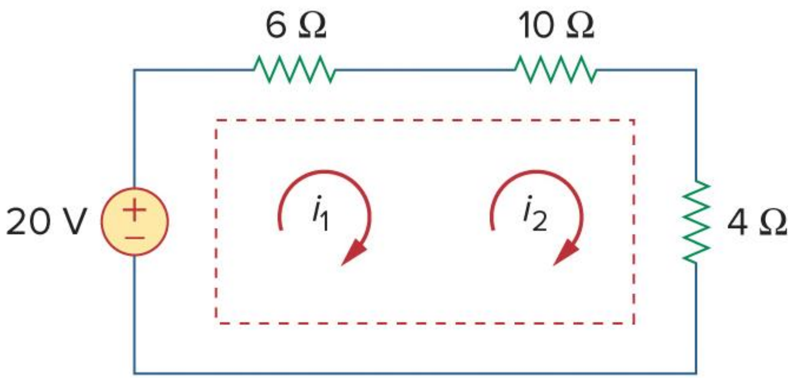

Supermesh is created by excluding the current source and resistor in series

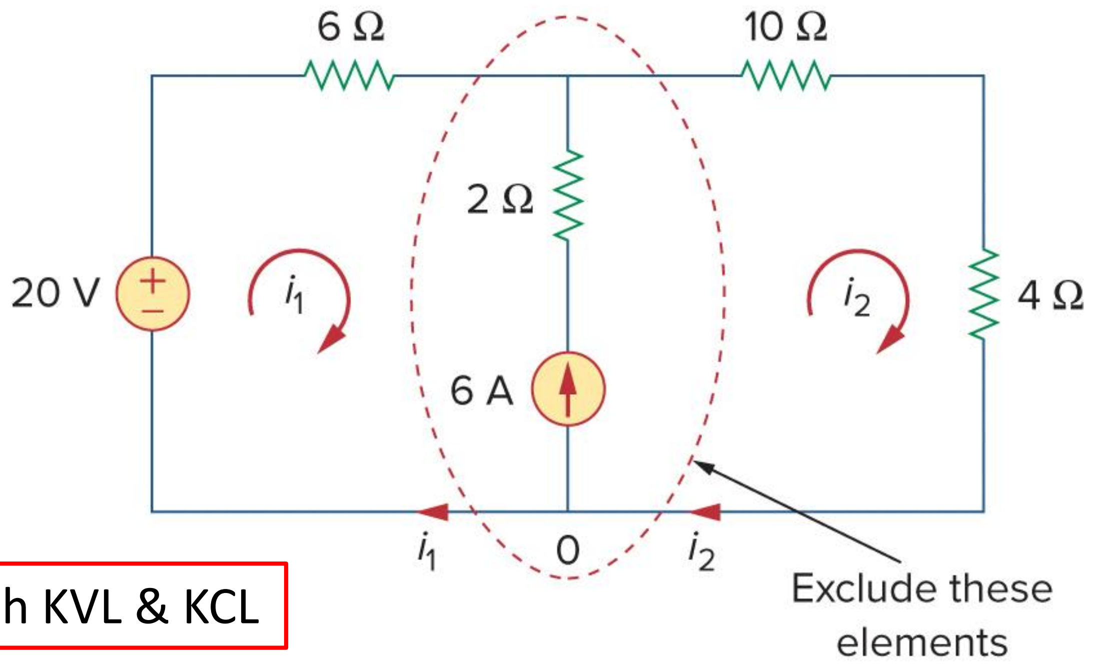
- Supermesh results when two meshes have a (dependent or independent) current source in common.

- If a circuit has two or more supermeshes that intersect, they should be combined to form a larger supermesh

# Mesh Analysis with Current Sources

- A Supermesh requires the application of both KVL and KCL




For supermesh: apply both KVL & KCL

- Apply KVL to the supermesh:

$$-20 + 6i_1 + 10i_2 + 4i_2 = 0$$

$$6i_1 + 14i_2 = 20$$

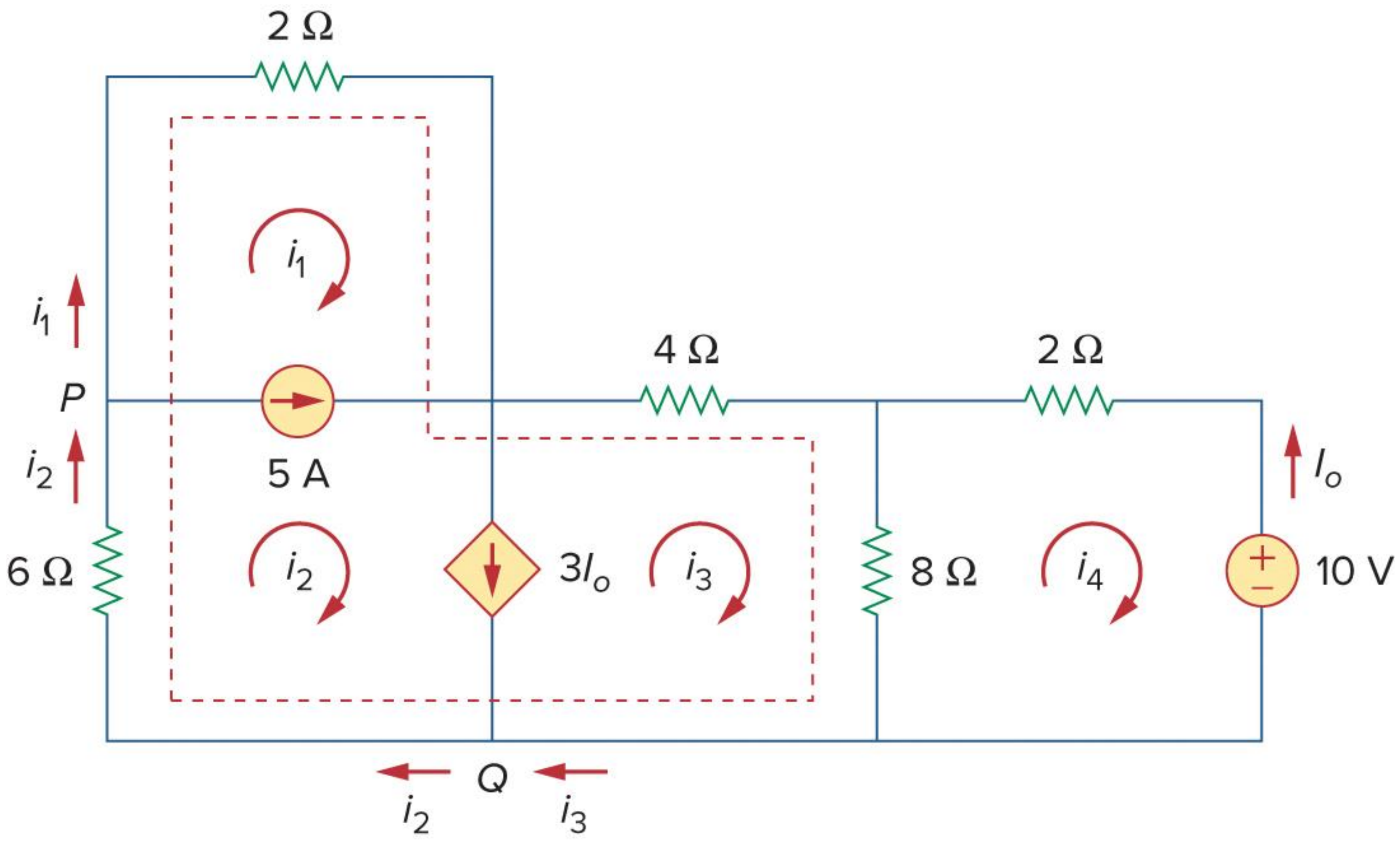
- Apply KCL to node zero (intersection of two meshes):

$$i_2 = i_1 + 6$$

$$i_1 = -3.2\ A \ \ \&\ \ i_2 = 2.8\ A$$

# Example 8

- For the circuit shown below, find $i_1$ to $i_4$ using mesh analysis.



# Solution

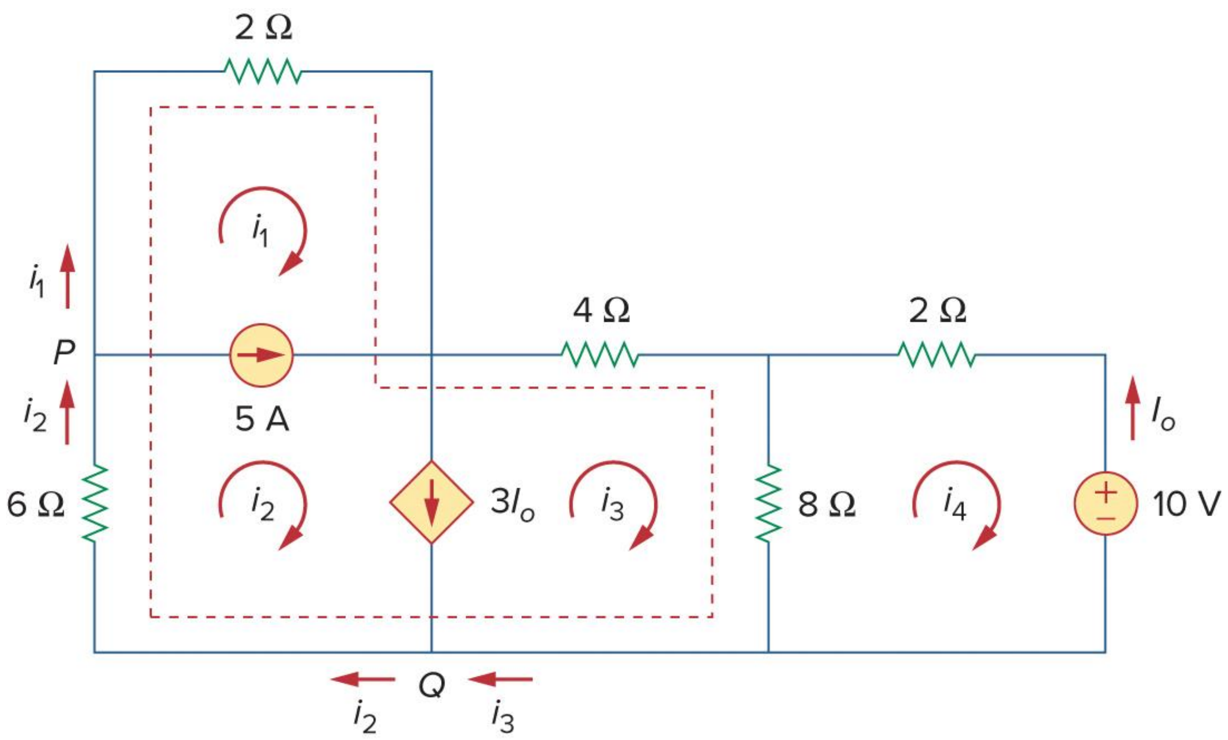
- Two supermeshes:
  - 1st one is between mesh 1 & 2
  - 2nd one is between mesh 2 & 3
- Combine them and exclude both current sources
- Apply KVL to the larger supermesh:

$$2i_1 + 4i_3 + 8(i_3 - i_4) + 6i_2 = 0$$

$$i_1 + 3i_2 + 6i_3 - 4i_4 = 0 \longrightarrow Eq\ 1$$

- For independent current source, apply KCL to node P:

$$i_2 = i_1 + 5 \longrightarrow Eq\ 2$$




- For dependent current source, apply KCL to node Q:

$$i_2 = i_3 + 3I_o \qquad I_o = -i_4$$

$$i_2 = i_3 - 3i_4 \longrightarrow Eq\ 3$$

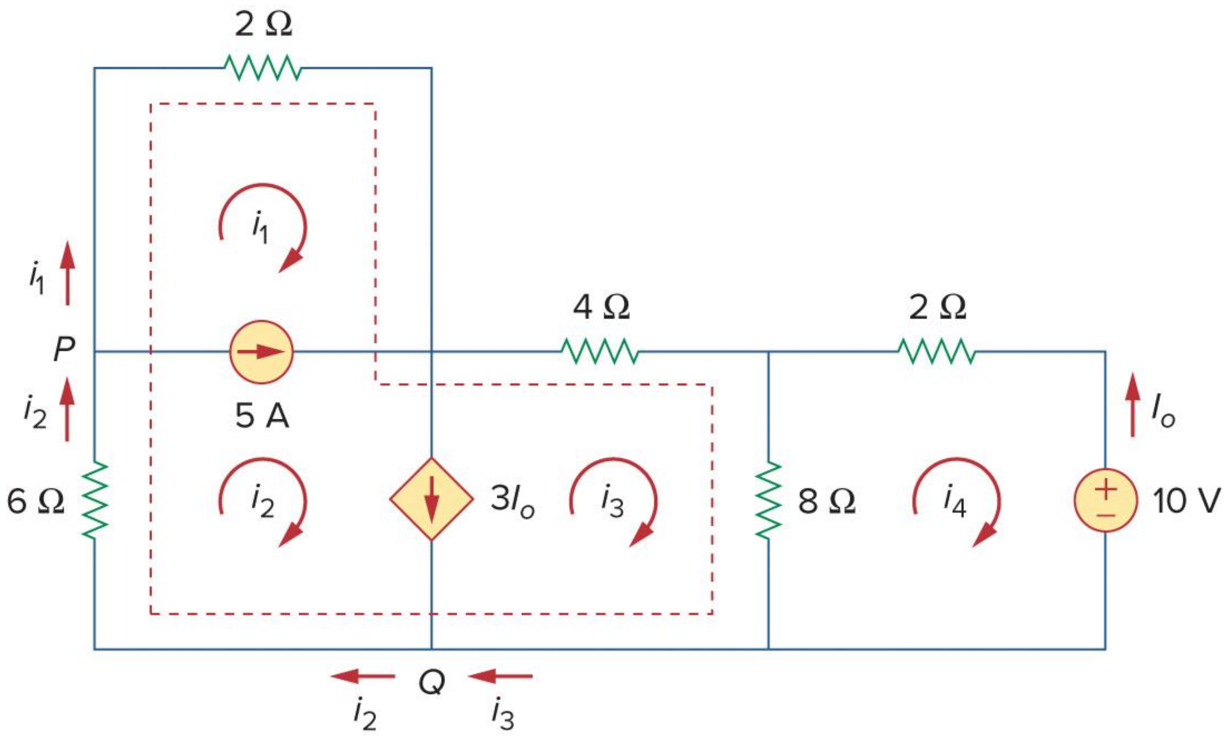
# Solution

- Apply KVL in mesh 4:

$$2i_4 + 8(i_4 - i_3) + 10 = 0$$

$$5i_4 - 4i_3 = -5 \longrightarrow Eq\ 4$$

$$\left.\begin{aligned} i_1 + 3i_2 + 6i_3 - 4i_4 &= 0 \\ i_2 &= i_1 + 5 \\ i_2 &= i_3 - 3i_4 \\ 5i_4 - 4i_3 &= -5 \end{aligned}\right\}$$




$$i_1 = -7.5\text{ A}, \qquad i_2 = -2.5\text{ A}, \qquad i_3 = 3.93\text{ A}, \qquad i_4 = 2.143\text{ A}$$

# Nodal versus Mesh Analysis

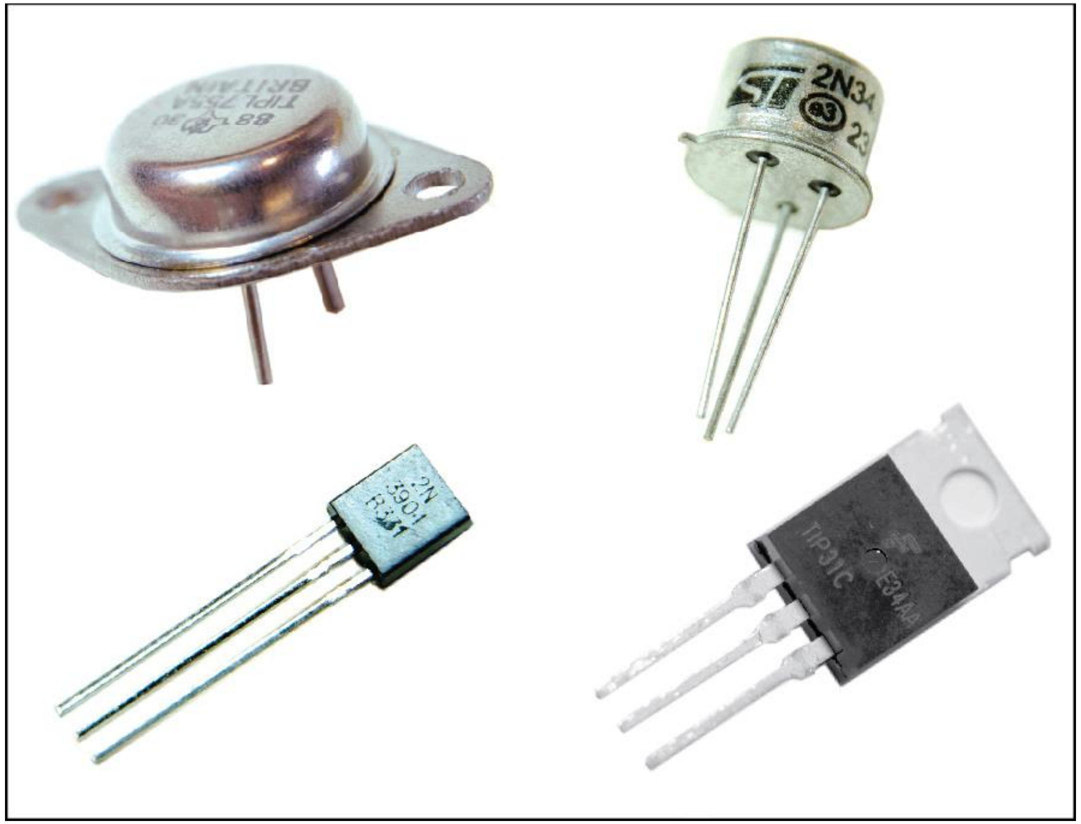
- Both methods provide a systematic way of analyzing a complex network.
- How do we know which method is better or more efficient?
- The choice of the better method is dictated by two factors.
- First factor: the nature of the particular network
  - Mesh analysis: more suitable if network contains many series-connected elements, voltage sources, or supermeshes
  - Nodal analysis: more suitable if network contains parallel-connected elements, current sources, or supernodes
  - Better to use nodal analysis for a circuit with fewer nodes than meshes
  - Better to use mesh analysis for a circuit with fewer meshes than nodes
- Second factor: Based on required information
  - If node voltages are required, apply node analysis
  - If branch or mesh currents are required, apply mesh analysis
- You must learn both methods!

# DC Transistor Circuits

- Transistors play essential role for the design of integrated circuits (IC).

- What is a transistor?
  - Current **Trans**ferring res**istor**
  - Three terminal semiconductor device

- Two types of transistors:
  - Bipolar Junction Transistor (BJT)
  - Field-Effect Transistor (FET)

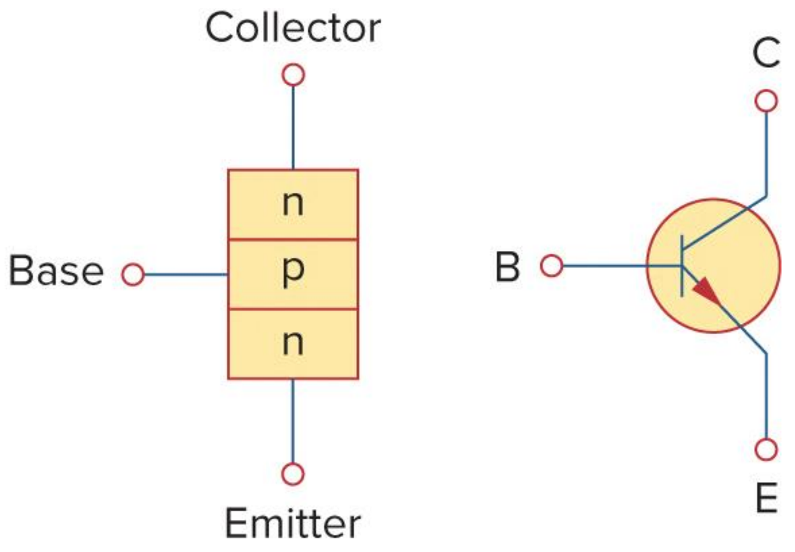



Various types of transistors

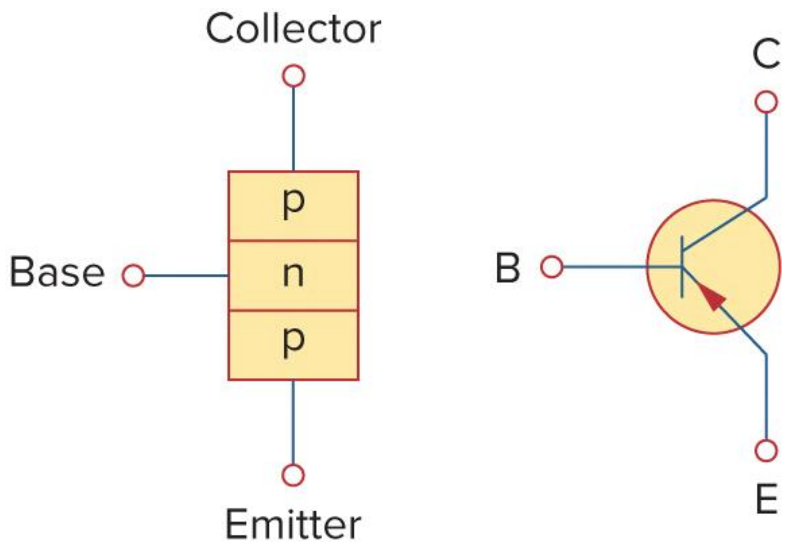
# DC Transistor Circuits

- Two types of Bipolar Junction Transistor (BJT)
  - npn
  - pnp

npn: Arrowhead pointing down

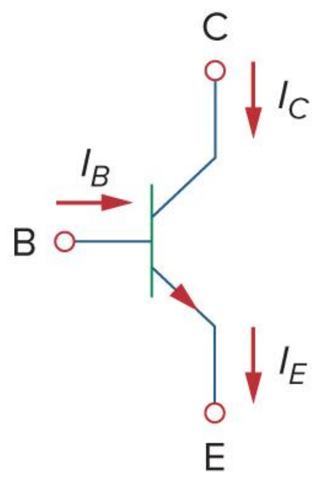



pnp: Arrowhead pointing up




- Three terminals: emitter (E), base (B), and collector (C)

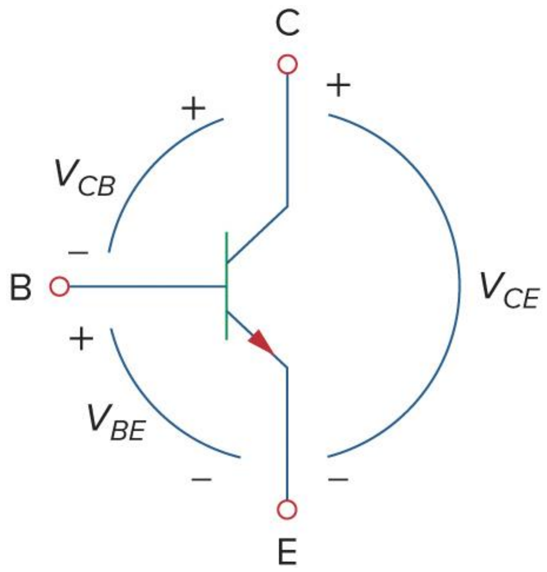
# DC Transistor Circuits




Apply KCL: $\sum i_{in} = \sum i_{out}$

$$\boxed{I_E = I_C + I_B}$$

$I_E$: emitter current
$I_C$: collector current
$I_B$: base current



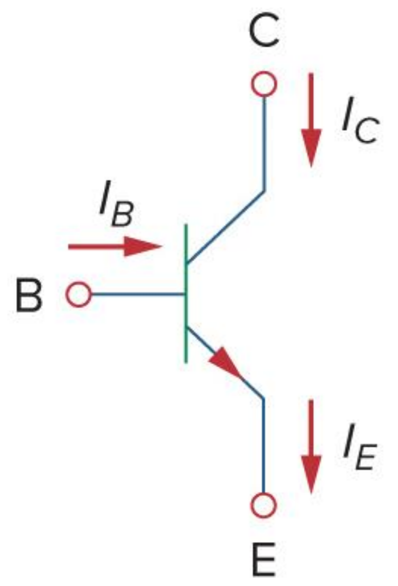

Apply KVL: $\sum_{m=1}^{M} V_m = 0$

$$V_{CE} - V_{BE} - V_{CB} = 0$$
or
$$V_{CE} + V_{EB} + V_{BC} = 0$$

$V_{CE}$: collector-emitter voltage
$V_{EB}$: emitter-base voltage
$V_{BC}$: base-collector voltage

# DC Transistor Circuits

- BJT: three modes of operation
  - Active mode
  - Cutoff mode
  - Saturation mode




- Operation in active mode:

$\boxed{V_{BE} \approx 0.7\ V}$ $\boxed{I_C = \alpha I_E}$ $\boxed{I_C = \beta I_B}$

$$I_E = I_C + I_B \Rightarrow I_E = \beta I_B + I_B \Rightarrow (1+\beta)\, I_B \Rightarrow \boxed{I_E = (1+\beta)\, I_B}$$

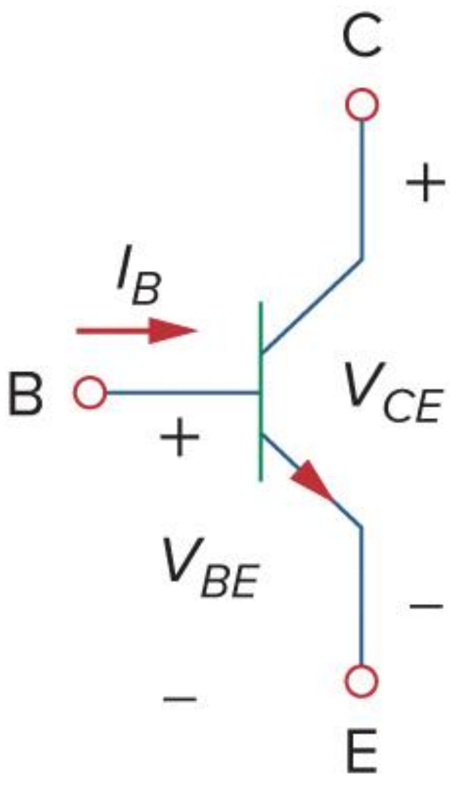
$$\alpha I_E = \beta I_B \Rightarrow \alpha \frac{I_E}{I_B} = \beta \Rightarrow \alpha \frac{(1+\beta)\, I_B}{I_B} = \beta \Rightarrow \alpha + \alpha\beta = \beta$$

$$\Rightarrow \alpha = \beta - \alpha\beta \Rightarrow \alpha = \beta(1-\alpha) \Rightarrow \boxed{\beta = \frac{\alpha}{1-\alpha}}$$

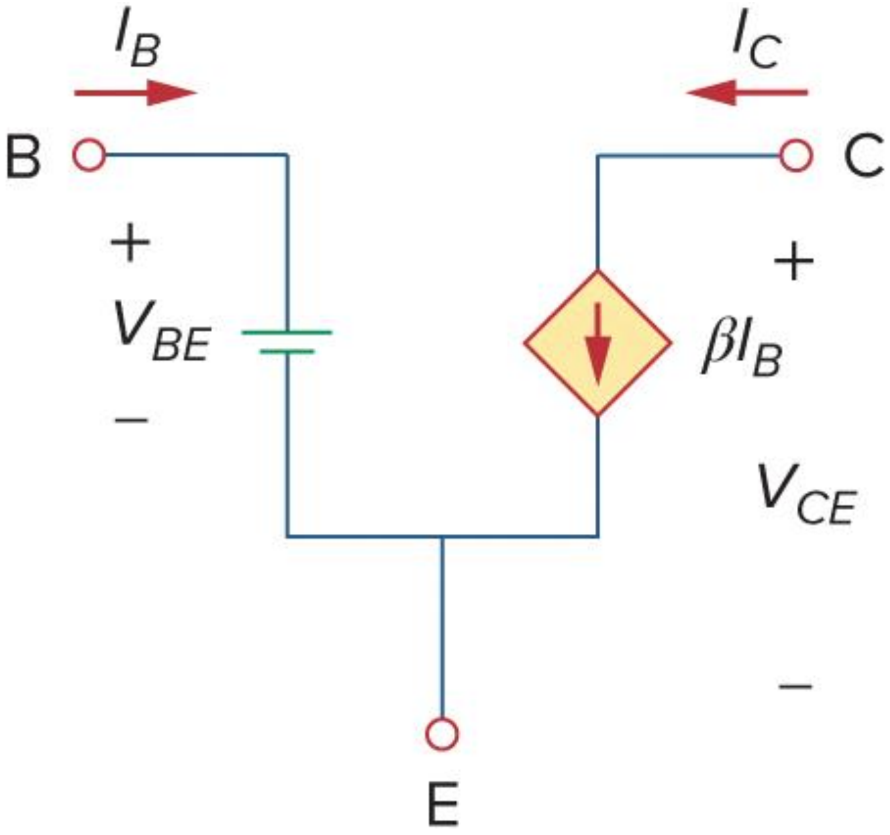
$\alpha$ : common-base current gain (in the range of 0.98 to 0.999)
$\beta$ : common-emitter current gain (in the range of 50 to 1000)
$\alpha$ and $\beta$ is the transistor properties and assume constant for a given transistor

# DC Transistor Circuits

- In active mode, the BJT can be modeled as a dependent current-controlled current source:



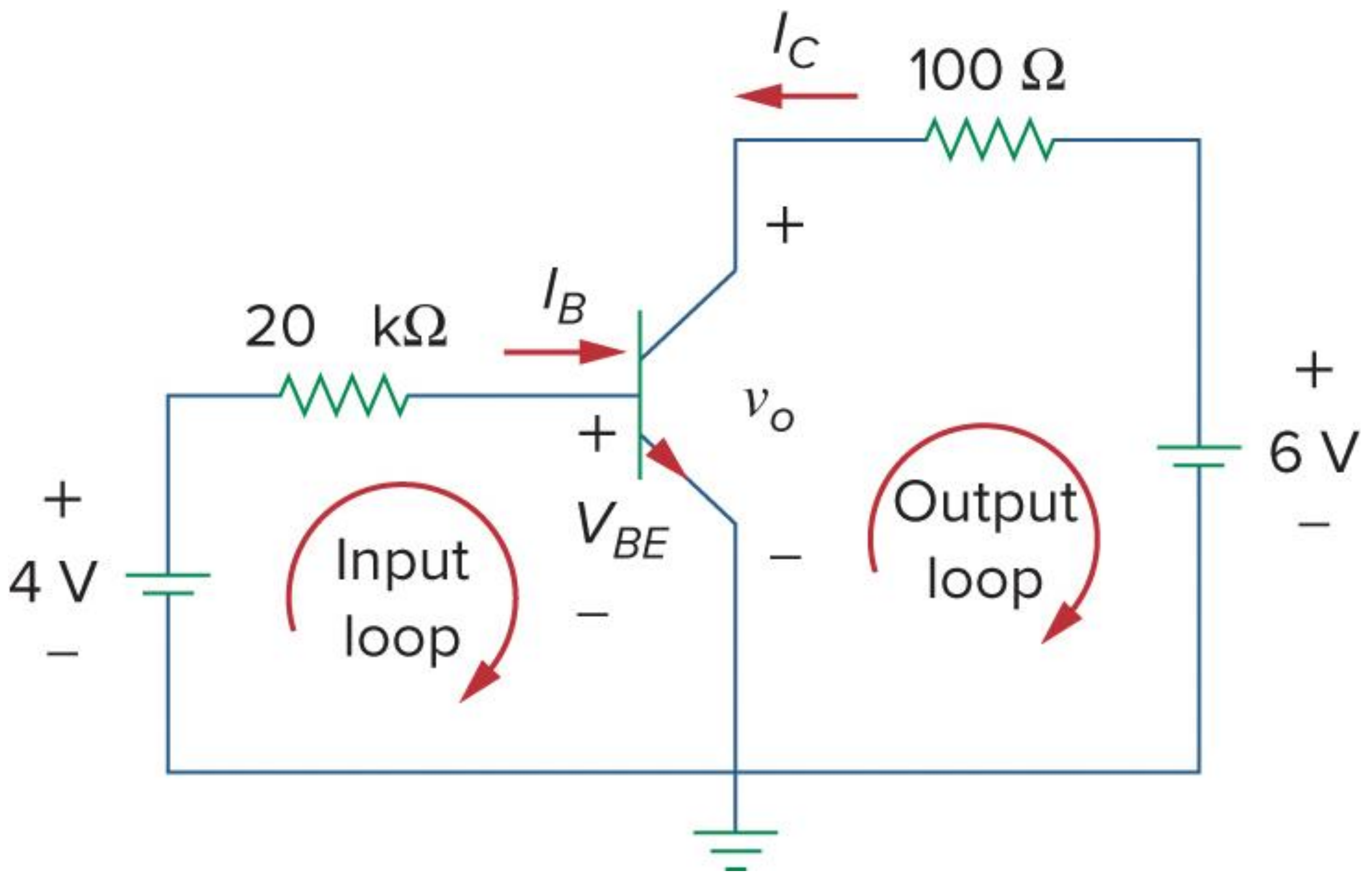

npn transistor




Its dc equivalent model

# Example 9

Find the $I_B$, $I_C$, and $v_0$ in the transistor shown below. Assume that the transistor operates in the active mode and that $\beta = 50$.



# Solution

For the input loop, KVL gives

$$-4 + I_B(20 \times 10^3) + V_{BE} = 0$$

Since $V_{BE} = 0.7$ V in the active mode,

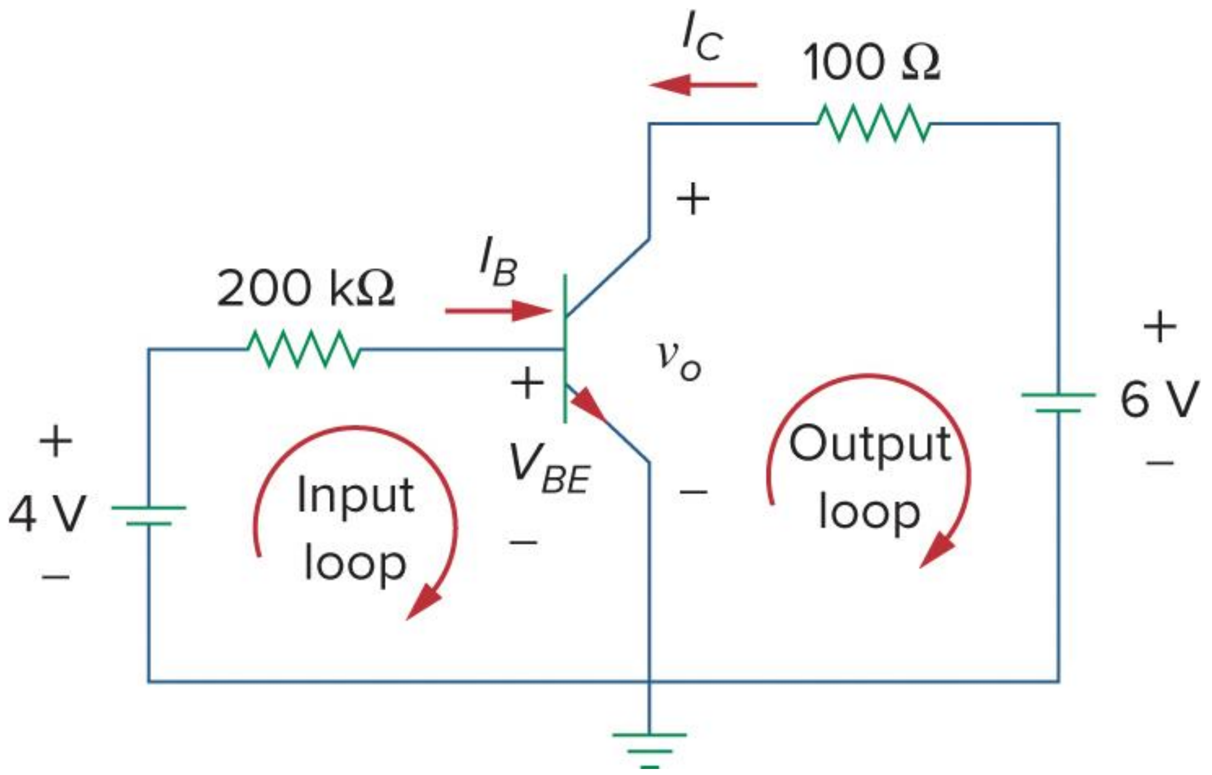
$$I_B = \frac{4 - 0.7}{20 \times 10^3} = 165\ \mu\text{A}$$

$$I_C = \beta I_B = 50 \times 165\ \mu\text{A} = 8.25\ \text{mA}$$

For the output loop, KVL gives

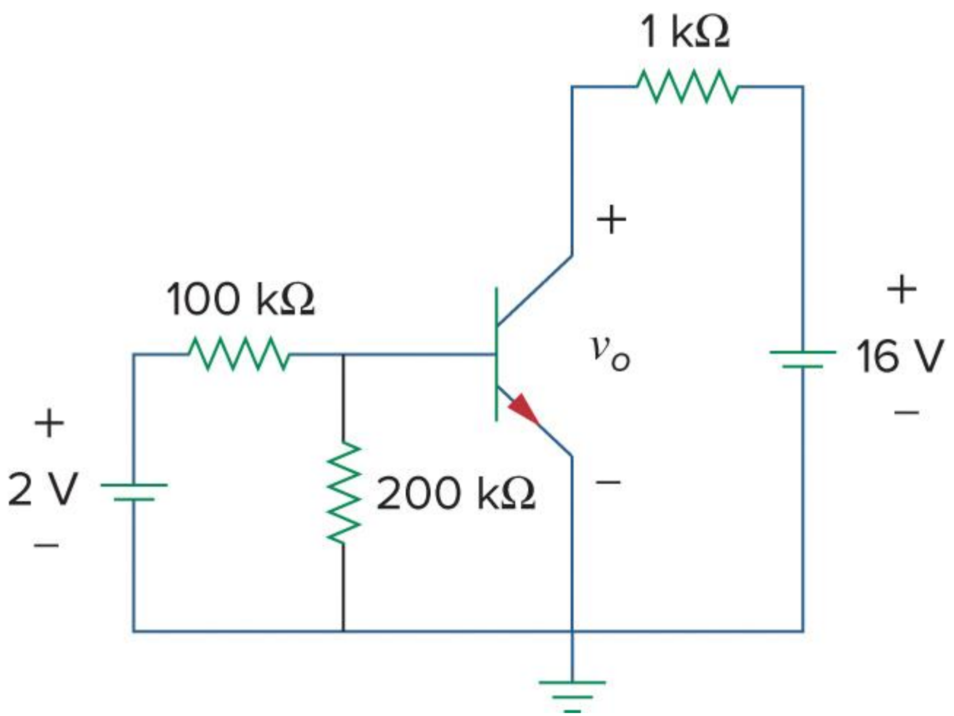
$$-v_o - 100 I_C + 6 = 0$$

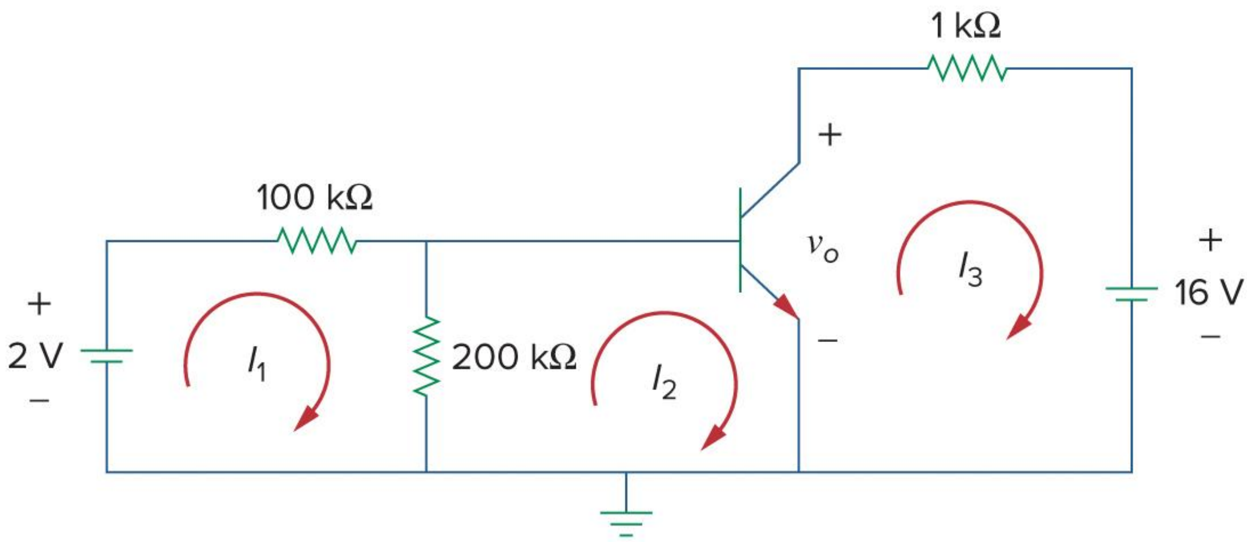
$$v_o = 6 - 100 I_C = 6 - 0.825 = 5.175\ \text{V}$$



# Example 11

- For the BJT circuit shown below, $\beta = 150$ and $V_{BE} = 0.7\ V$. Find $v_0$.



# Solution

- Method 1: Solving with **mesh analysis**

1st loop:

$$-2 + 100\mathrm{k}I_1 + 200\mathrm{k}(I_1 - I_2) = 0$$

$$3I_1 - 2I_2 = 2 \times 10^{-5} \longrightarrow Eq\ 1$$

2nd loop:

$$200\mathrm{k}(I_2 - I_1) + V_{BE} = 0$$

$$-2I_1 + 2I_2 = -0.7 \times 10^{-5} \longrightarrow Eq\ 2$$

2 equations and
2 unknowns

$I_1 = 1.3 \times 10^{-5}\mathrm{A}$ and $I_2 = (-0.7 + 2.6)10^{-5}/2 = 9.5\ \mu\mathrm{A}$

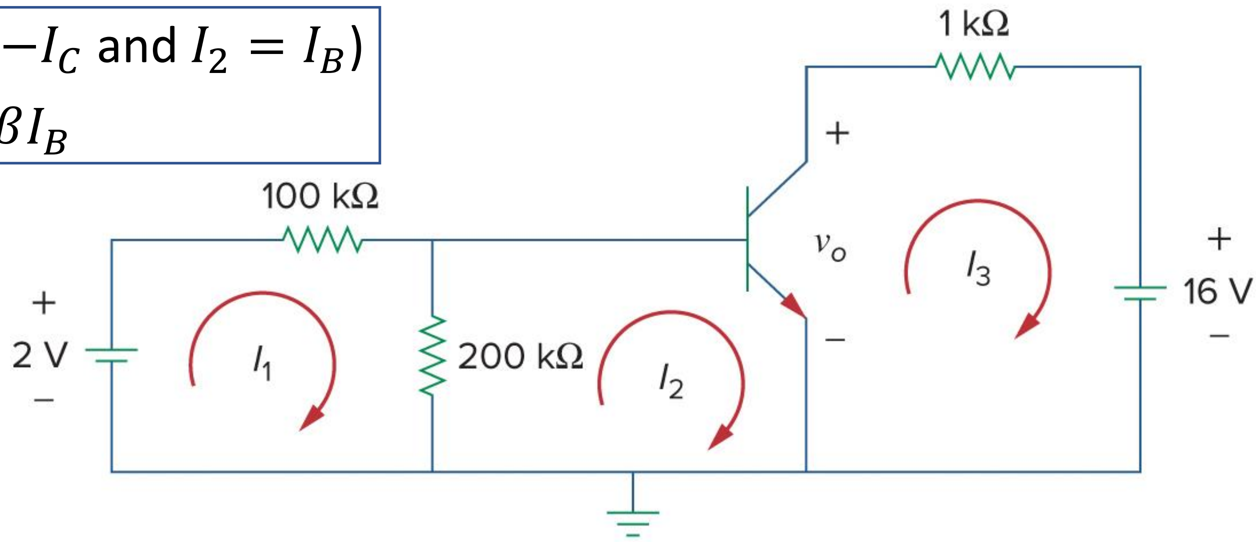
Since $I_3 = -150I_2 = -1.425\ \mathrm{mA}$

$(I_3 = -I_C$ and $I_2 = I_B)$
$I_C = \beta I_B$

3rd loop:

$$-v_o + {}^{1}\mathrm{k}I_3 + 16 = 0$$

$$v_o = -1.425 + 16 = \mathbf{14.575\ V}$$



# Solution

- Method 2: Solving with **nodal analysis**
- Replace transistor with its equivalent circuit

At node number 1: $V_1 = 0.7$ V

Apply KCL:

$$(0.7 - 2)/100\text{k} + 0.7/200\text{k} + I_B = 0$$

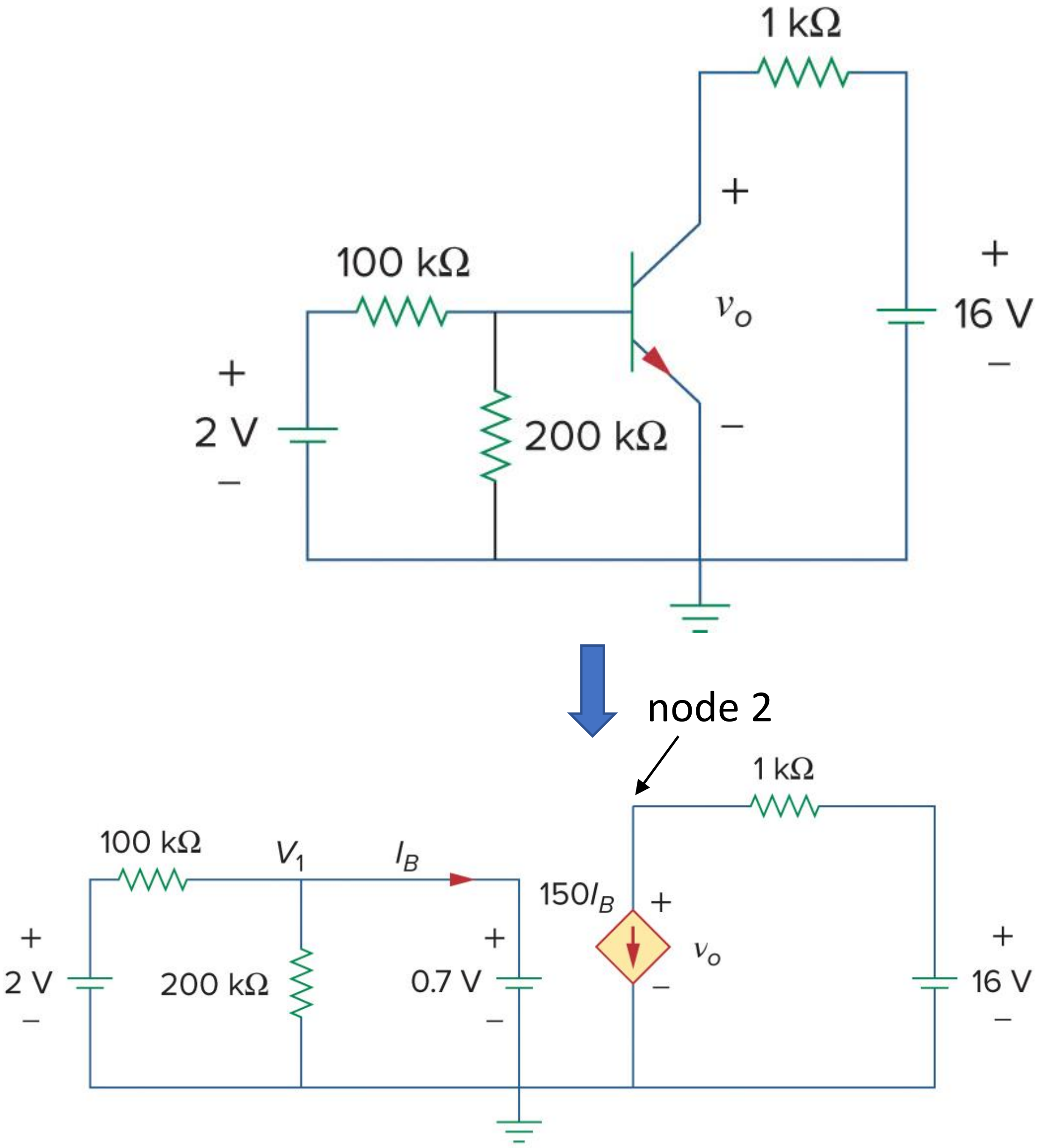
$$I_B = 9.5\ \mu\text{A}$$

At node number 2 we have:

Apply KCL:

$$150 I_B + (v_o - 16)/1\text{k} = 0$$

$$v_o = 16 - 150 \times 10^3 \times 9.5 \times 10^{-6} = \mathbf{14.575\ V}$$



# PSpice

- What is PSpice?
  - Free computer software circuit analysis program
  - Allows you to simulate and analyze a circuit
  - Helpful program in determining the voltages and currents in a circuit
  - Use online sources (YouTube and google) for a tutorial on how to use the PSpice program