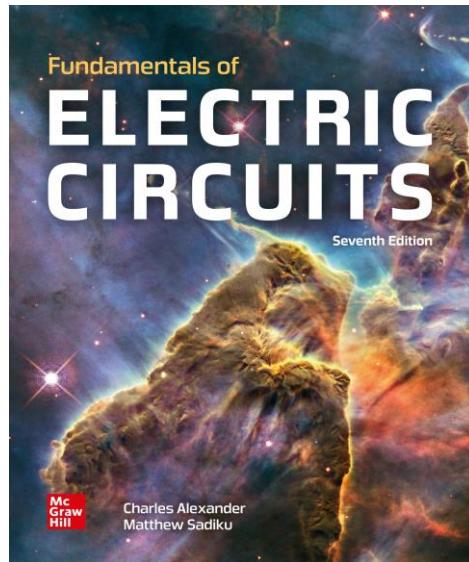


# **EHB 211E**

## **Basics of Electrical Circuits**

*Asst. Prof. Onur Kurt*

## **Methods of Analysis**



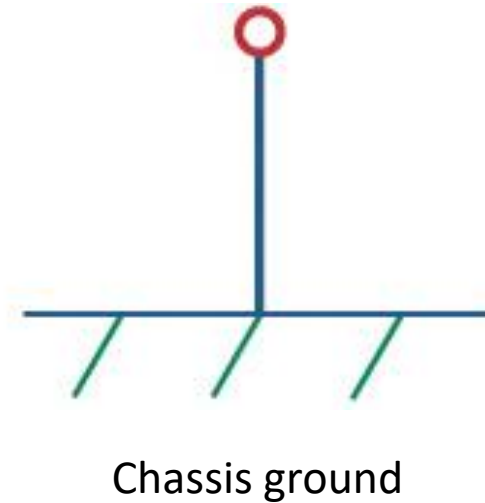
- Provide a general procedure for analyzing circuit using node voltages
- In nodal analysis, node voltages needed to be found
- Steps to determine node voltages:
  - Select a node as the reference node. Assign voltages  $v_1, v_2, \dots, v_{n-1}$  to the remaining  $n-1$  nodes. The voltages are referenced 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)



Mostly used



# Example 1

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

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

$$\text{At node 1: } I_1 = I_2 + i_1 + i_2$$

$$\text{At node 2: } I_2 + i_2 = i_3$$

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

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

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

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

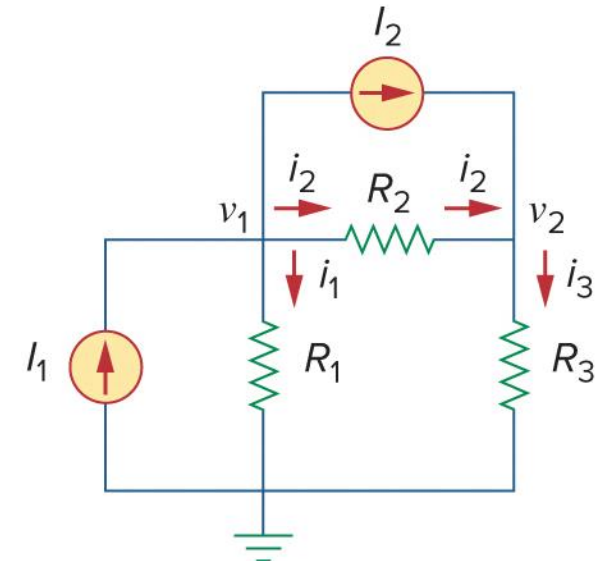
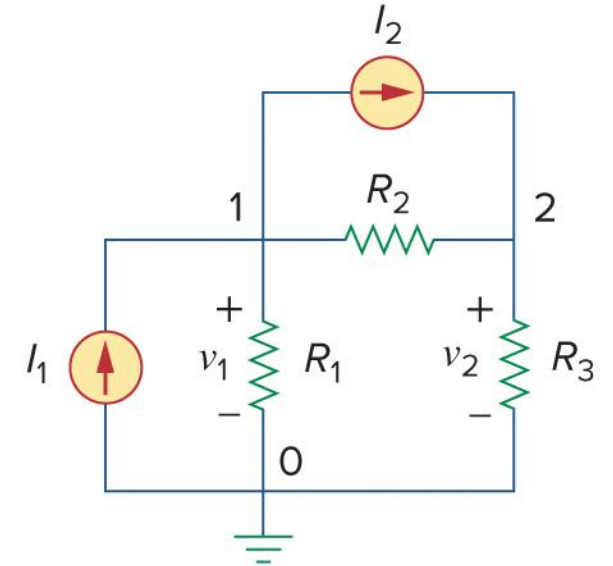
$$I_1 = I_2 + \frac{v_1}{R_1} + \frac{v_1 - v_2}{R_2} \quad \text{or} \quad I_1 = I_2 + G_1 v_1 + G_2(v_1 - v_2)$$

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

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

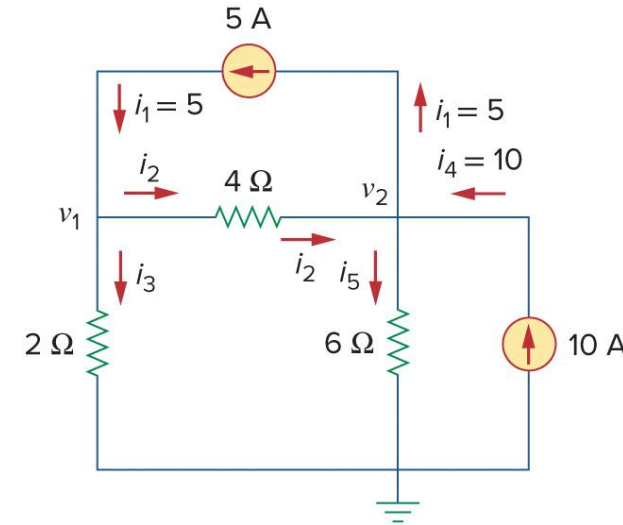
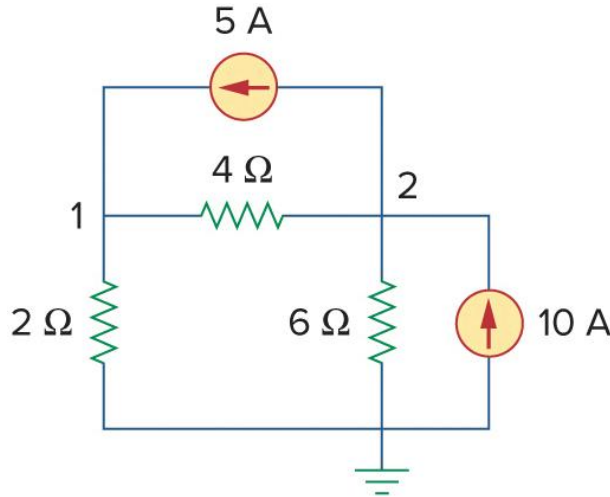
$$i = \frac{v_{higher} - v_{lower}}{R}$$

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



# Example 2

- Calculate the node voltages in the circuit shown below



## Solution:

At node 1:  $i_1 = i_2 + i_3 \Rightarrow 5 = i_2 + i_3$

$$i_2 = \frac{v_1 - v_2}{4}, i_3 = \frac{v_1 - 0}{2}$$

$$5 = \frac{v_1 - v_2}{4} + \frac{v_1}{2} \rightarrow \text{Eq 1}$$

$$\frac{v_1 - v_2}{4} + \frac{v_1}{2} = 5$$

$$\frac{v_1 - v_2}{4} - \frac{v_2}{6} = -5$$

At node 2:  $i_2 + i_4 = i_1 + i_5 \Rightarrow i_2 + 10 = 5 + i_5$

$$i_5 = \frac{v_2 - 0}{6}$$

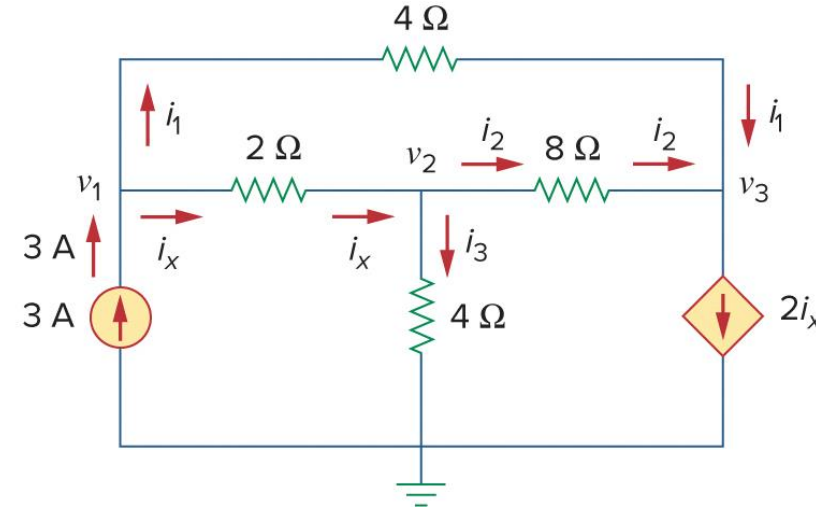
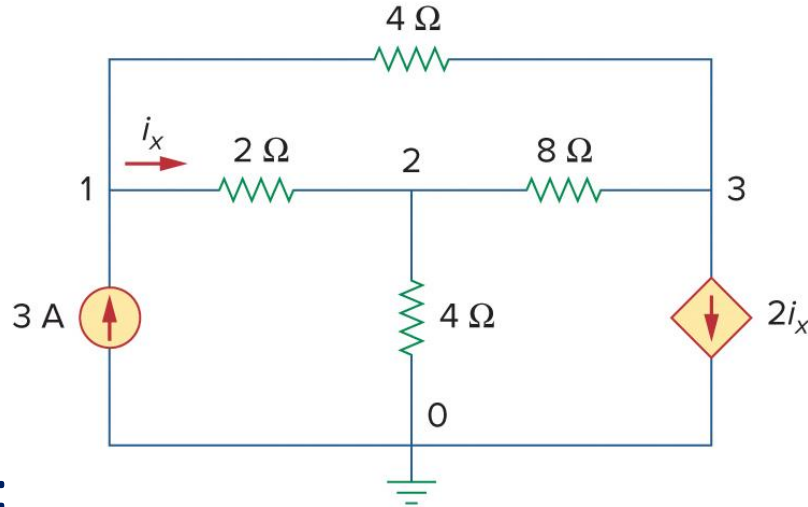
$$\frac{v_1 - v_2}{4} + 10 = 5 + \frac{v_2}{6} \Rightarrow \frac{v_1 - v_2}{4} - \frac{v_2}{6} = -5 \rightarrow \text{Eq 2}$$

$$v_1 = \frac{40}{3} = 13.333 \text{ V}$$

$$v_2 = 20 \text{ V}$$

# Example 3

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



## Solution:

$$\left. \begin{array}{l} \text{At node 1: } 3 = i_1 + i_x \\ \text{At node 2: } i_x = i_2 + i_3 \\ \text{At node 3: } i_1 + i_2 = 2i_x \end{array} \right\} \begin{array}{l} i_1 = \frac{v_1 - v_3}{4} \\ i_2 = \frac{v_2 - v_3}{8} \\ i_3 = \frac{v_2}{4} \end{array} \quad i_x = \frac{v_1 - v_2}{2}$$

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

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

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

3 equation and  
3 unknowns

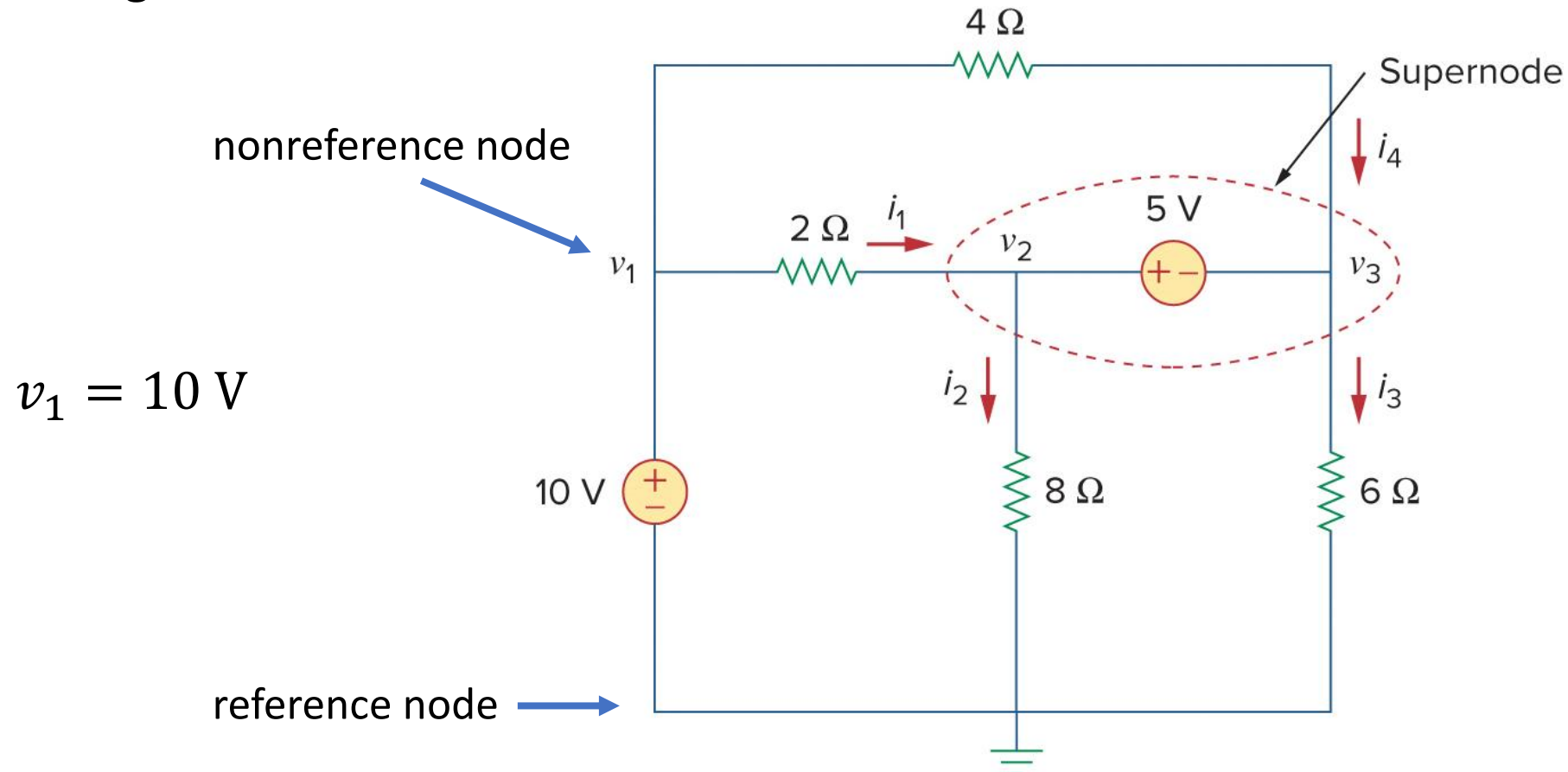
$$v_1 = 4.8 \text{ V}$$

$$v_2 = 2.4 \text{ V}$$

$$v_3 = -2.4 \text{ V}$$

# 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.



# 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

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

$$\text{At supernode node: } i_1 + i_4 = i_2 + i_3$$

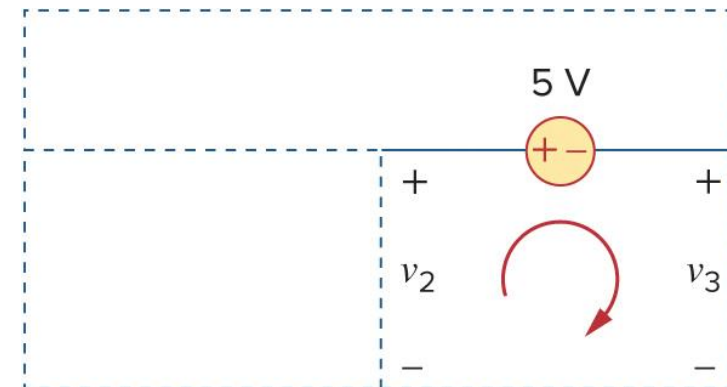
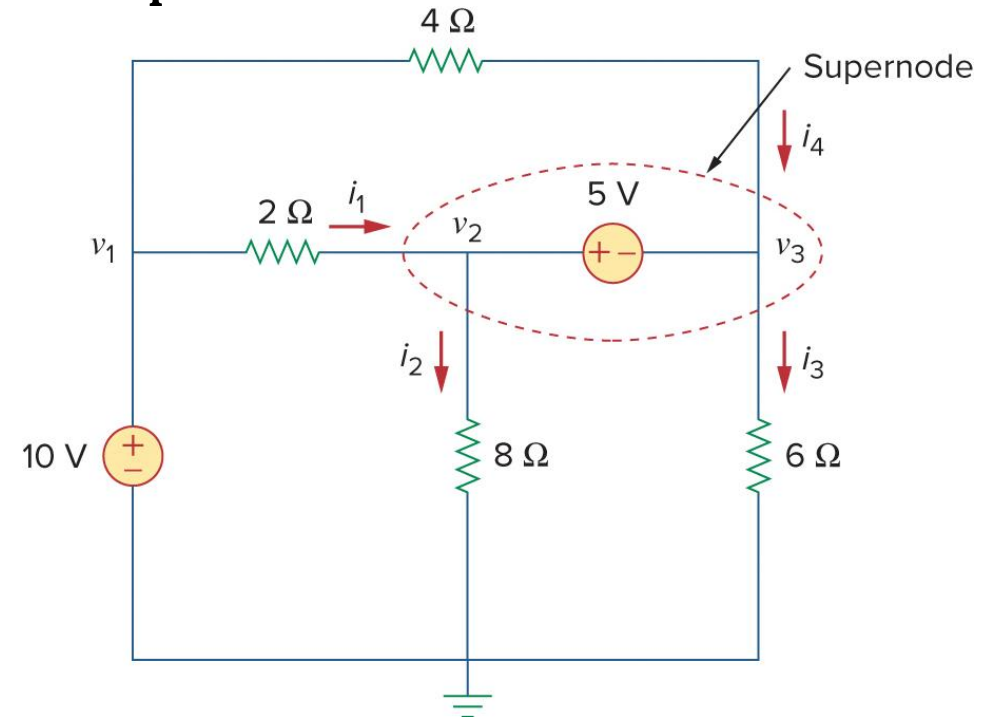
$$i_1 = \frac{v_1 - v_2}{2}, \quad i_2 = \frac{v_2}{8}, \quad i_3 = \frac{v_3}{6}, \quad i_4 = \frac{v_1 - v_3}{4}$$

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

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

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

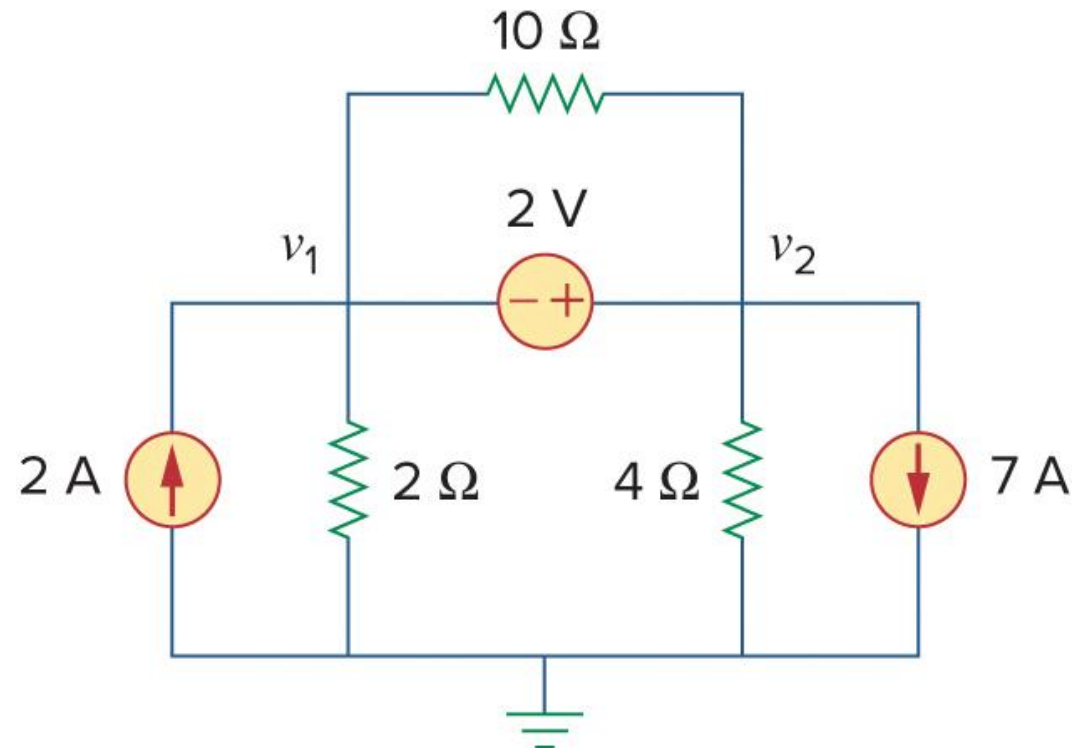
Supernode requires the application of both KCL and KVL



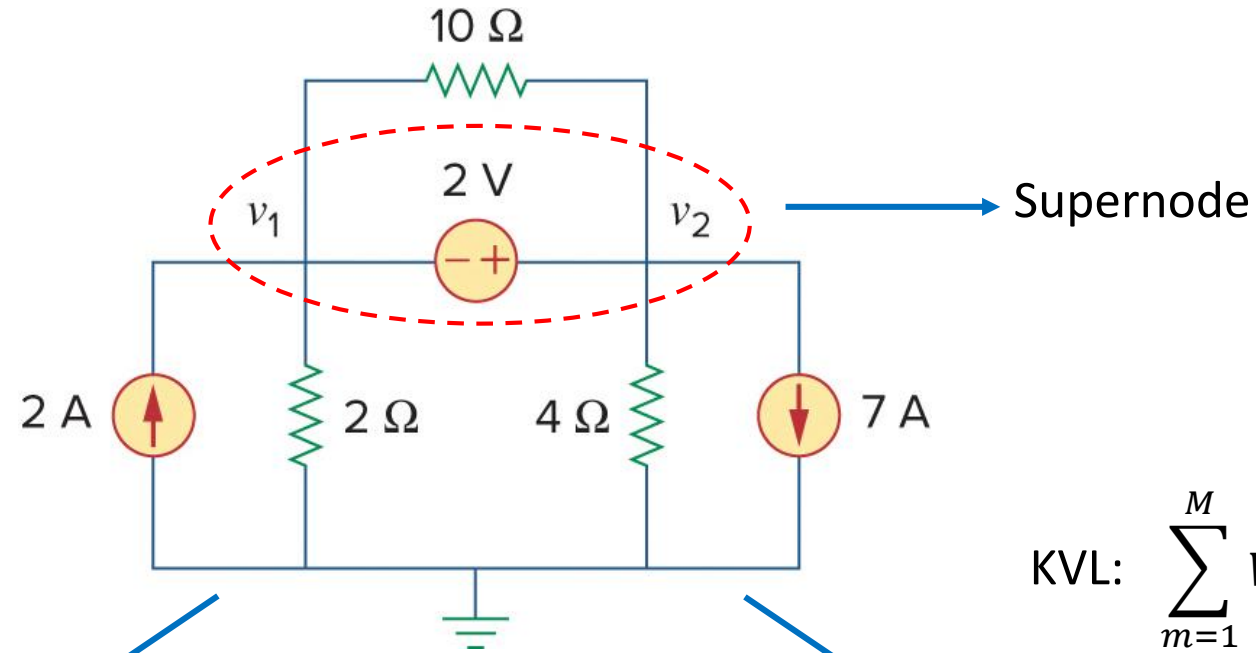


## Example 4

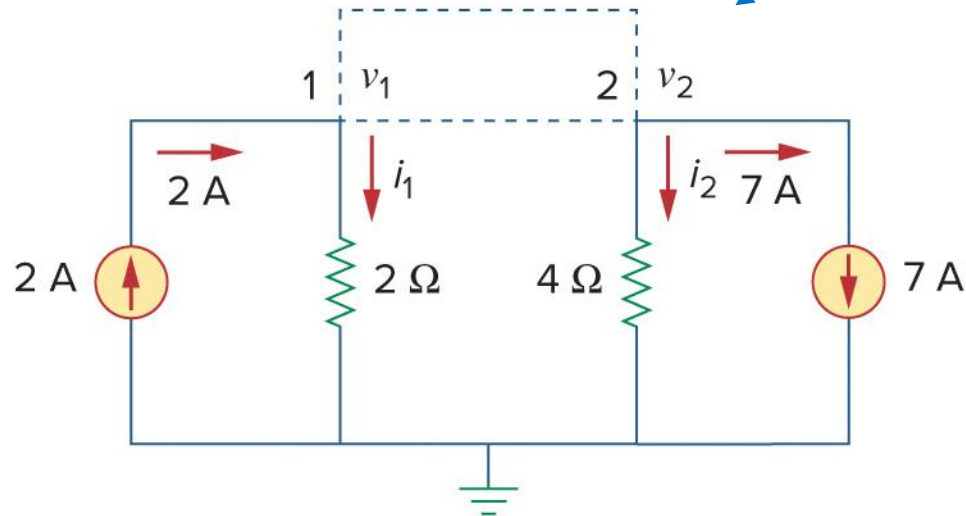
- For the circuit shown below, find the node voltages.



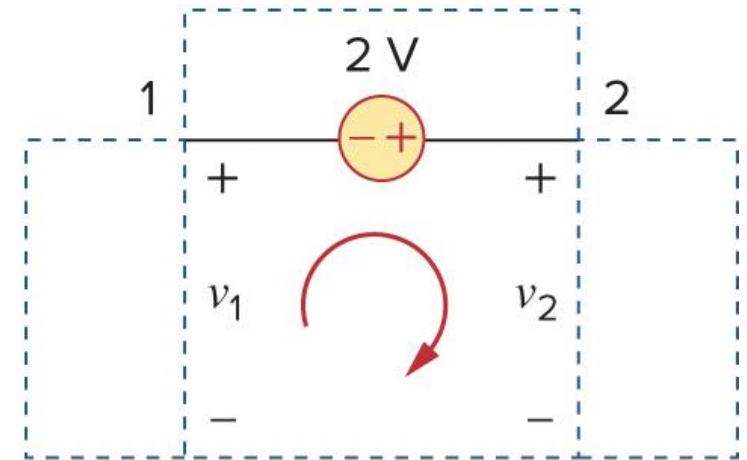
# Solution



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



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



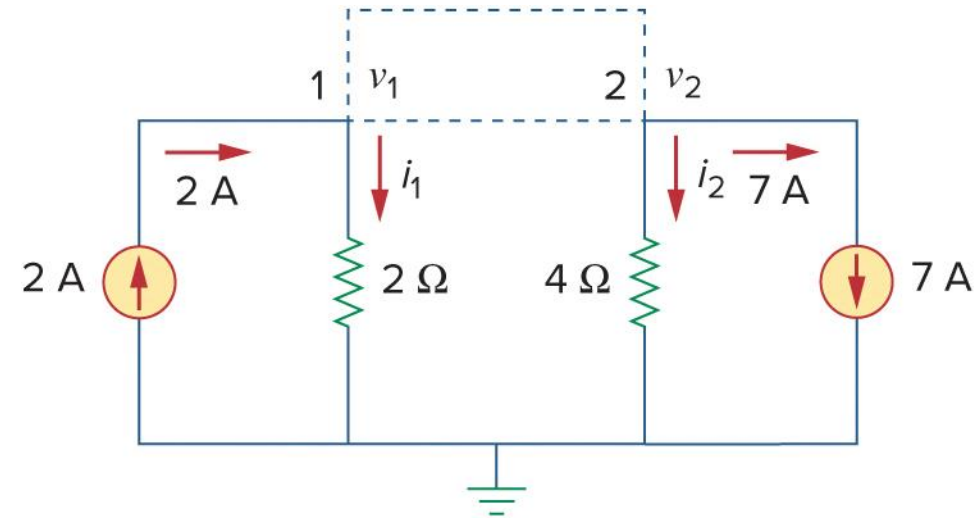
# Solution

Apply KCL at supernode:

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

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

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

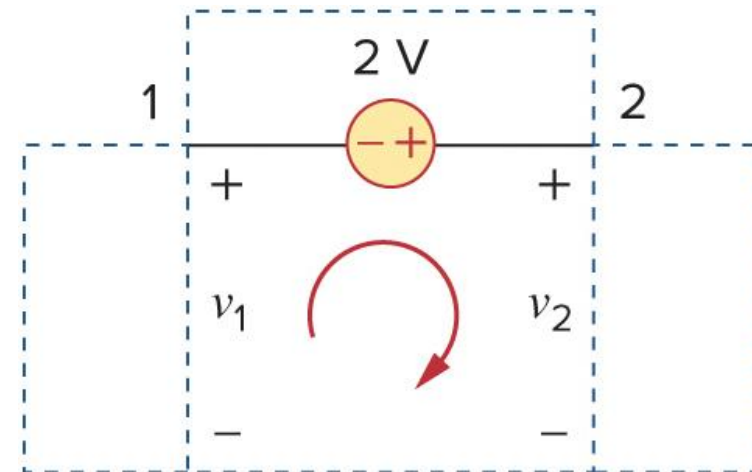


Apply KVL at supernode:

$$-v_1 - 2 + v_2 = 0 \Rightarrow -v_1 + v_2 = 2 \rightarrow \text{Eq 2}$$

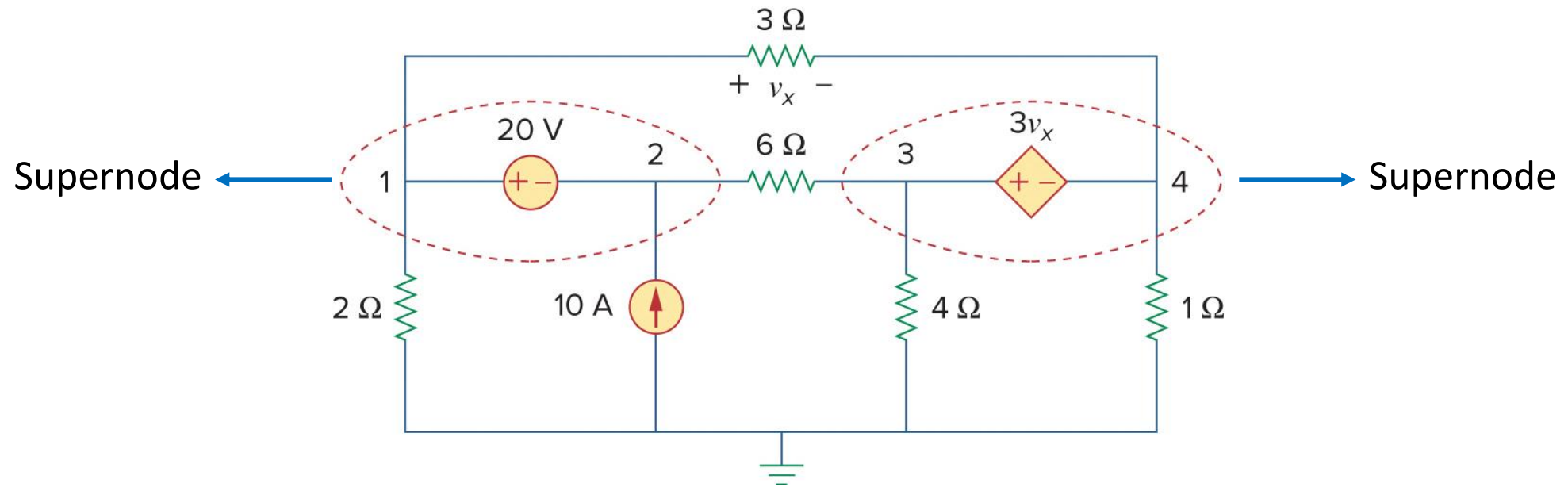
2 eqs and 2 unknowns:

$$\left. \begin{array}{l} 2v_1 + v_2 = -20 \\ -v_1 + v_2 = 2 \end{array} \right\} \begin{array}{l} v_1 = -7.333 \text{ V} \\ v_2 = -5.333 \text{ V} \end{array}$$



# Example 5

- 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

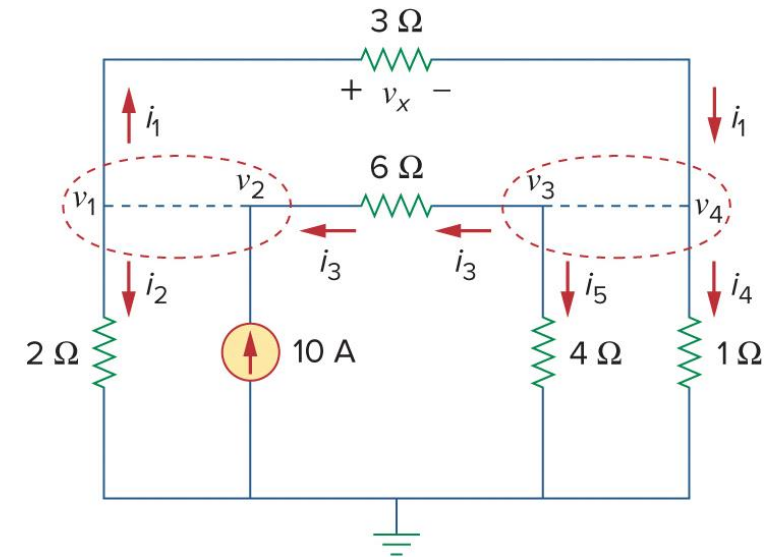
$$5v_1 + v_2 - v_3 - 2v_4 = 60$$

Apply KCL at supernode 3 and 4:

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

or

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



# Solution

Apply KVL at loop 1:

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

Apply KVL at loop 2:

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

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

Apply KVL at loop 3:

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

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

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

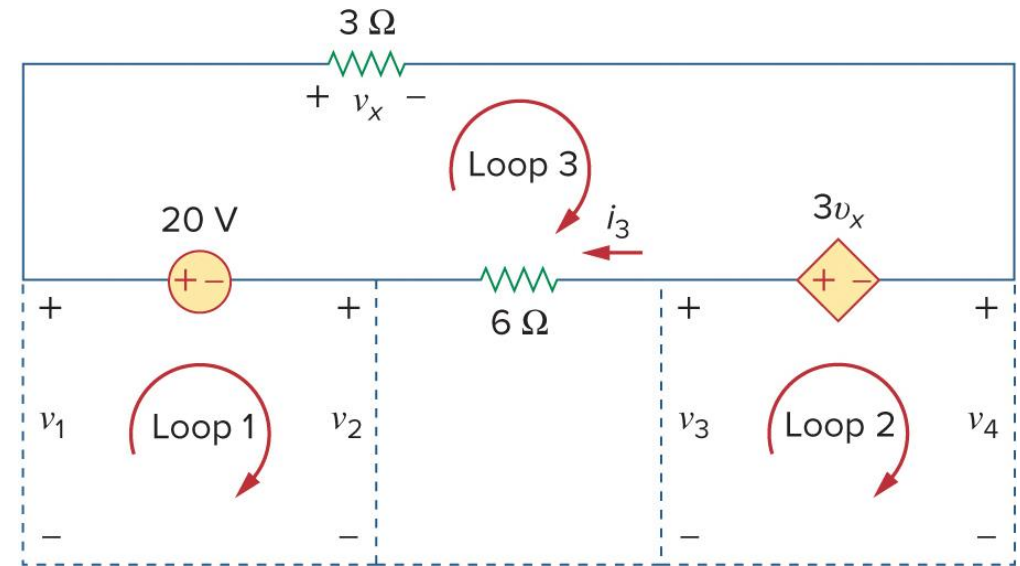
$$v_1 = 26.67 \text{ V}$$

$$v_2 = 6.667 \text{ V}$$

$$v_3 = 173.33 \text{ V}$$

$$v_4 = -46.67 \text{ V}$$

5 eqs and 4 unknowns:

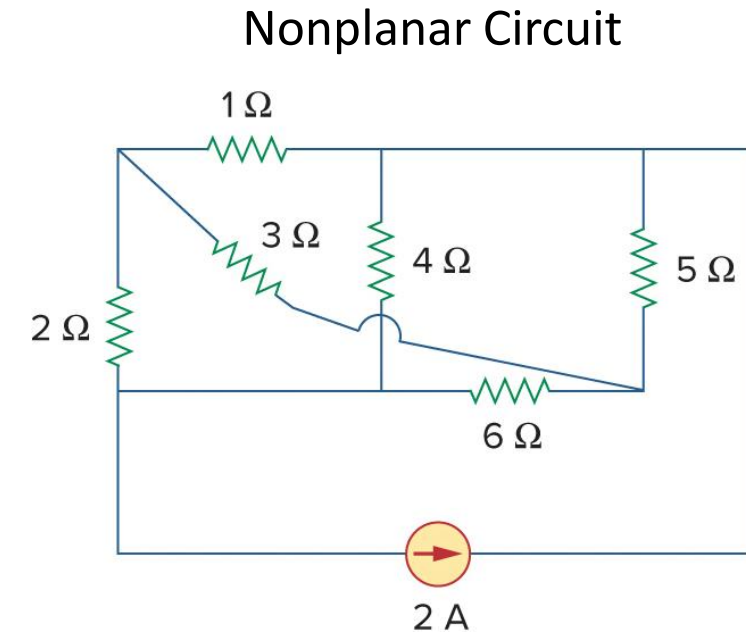
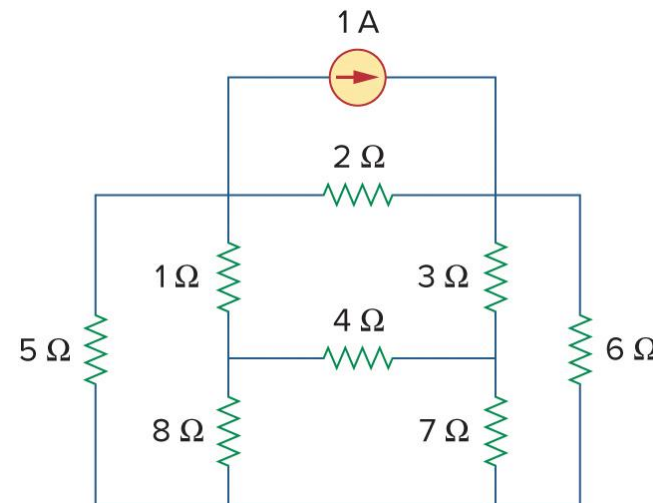
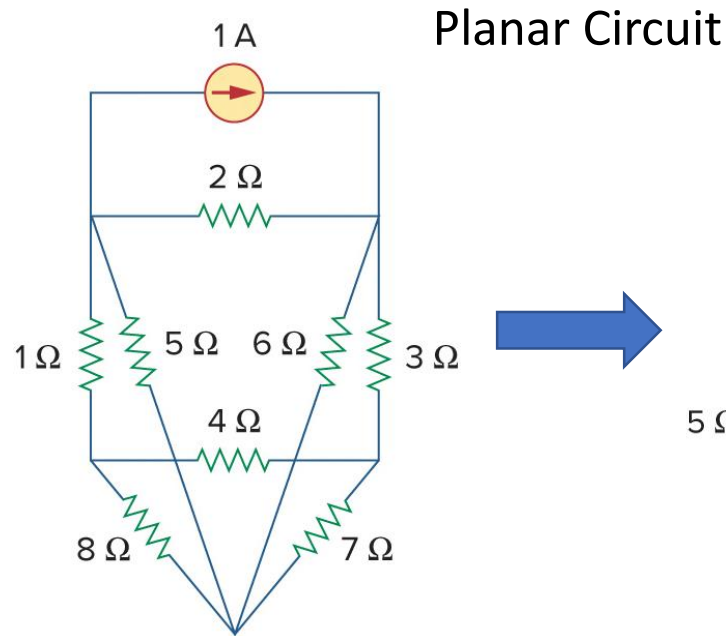


$$\left. \begin{aligned} 5v_1 + v_2 - v_3 - 2v_4 &= 60 \\ 4v_1 + 2v_2 - 5v_3 - 16v_4 &= 0 \end{aligned} \right\} \text{KCL}$$

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

# 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.

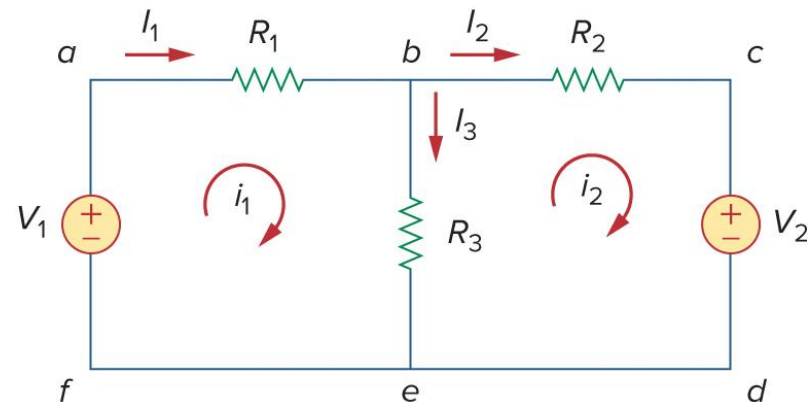


Nodal analysis applies KCL to find unknown voltages (For supernode: apply both KCL & KVL)  
 Mesh analysis applies KVL to find unknown currents (For supermesh: apply both KVL & KCL)

# 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  $i_1, i_2, \dots, i_n$  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 6

- Obtain branch currents using mesh analysis
- 1<sup>st</sup>: assign mesh currents ( $i_1$  and  $i_2$ ) to meshes 1 and 2
- Direction of mesh currents is chosen arbitrarily (clockwise)
- 2<sup>nd</sup>: apply KVL to mesh 1:

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

$$(R_1 + R_3)i_1 - R_3 i_2 = V_1 \rightarrow \text{Eq 1}$$

- Apply KVL to mesh 2:

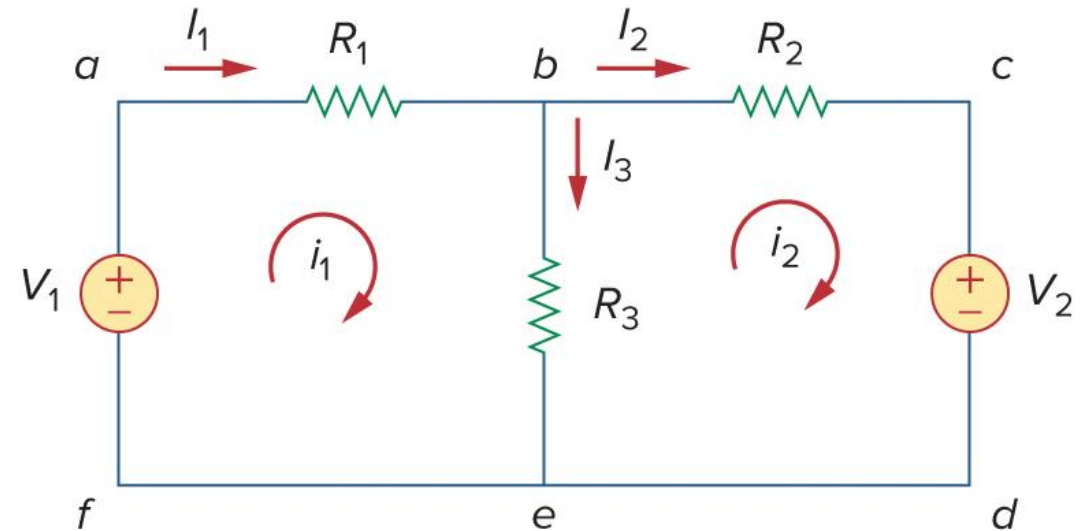
$$R_2 i_2 + V_2 + R_3(i_2 - i_1) = 0$$

$$-R_3 i_1 + (R_2 + R_3)i_2 = -V_2 \rightarrow \text{Eq 2}$$

- Last step is to solve for the mesh currents:

Equations in matrix form:

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



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

# Example 7

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

## Solution:

- 1<sup>st</sup>: assign mesh currents
- 2<sup>nd</sup>: apply KVL to mesh 1:

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

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

- Apply KVL to mesh 2:

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

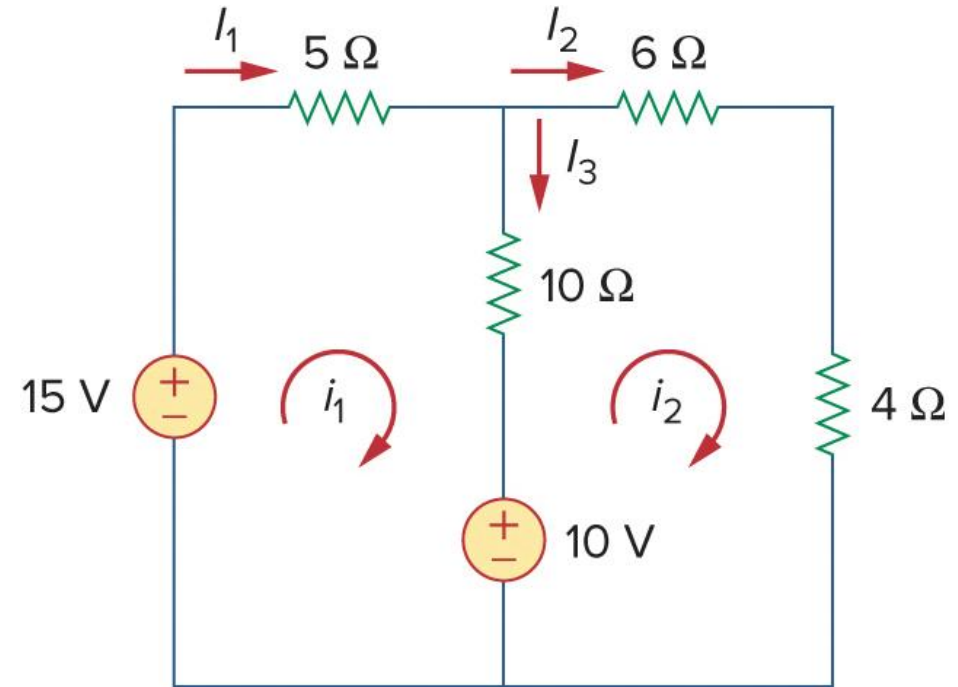
$$i_1 = 2i_2 - 1 \rightarrow Eq\ 2$$

- Substitute Eq 2 into Eq 1:

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

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

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



# Example 8

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

## Solution:

- Apply KVL to three meshes
- For mesh 1:  

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

$$11i_1 - 5i_2 - 6i_3 = 12 \rightarrow \text{Eq 1}$$
- For mesh 2:  

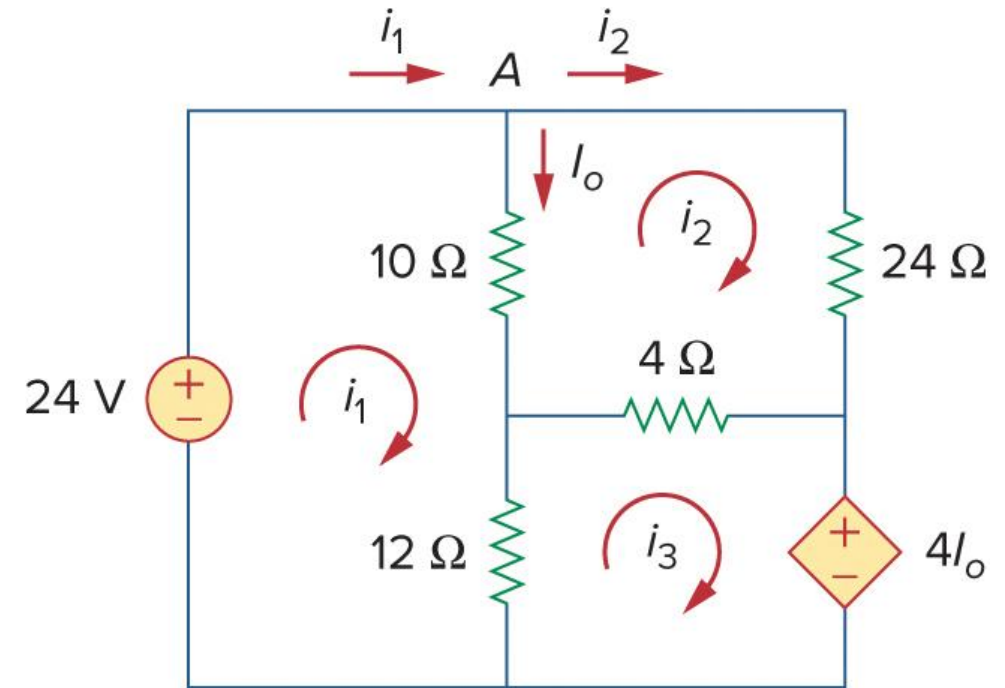
$$24i_2 + 4(i_2 - i_3) + 10(i_2 - i_1) = 0$$

$$-5i_1 + 19i_2 - 2i_3 = 0 \rightarrow \text{Eq 2}$$
- For mesh 3:  

$$4I_o + 12(i_3 - i_1) + 4(i_3 - i_2) = 0$$
- At node A, KCL:  $I_o = i_1 - i_2$   

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

$$-i_1 - i_2 + 2i_3 = 0 \rightarrow \text{Eq 3}$$



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

$$i_1 = \frac{\Delta_1}{\Delta} \quad i_2 = \frac{\Delta_2}{\Delta} \quad i_3 = \frac{\Delta_3}{\Delta} \quad \text{where } \Delta \text{ is determinant} \quad \begin{bmatrix} 11 & -5 & -6 \\ -5 & 19 & -2 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} 12 \\ 0 \\ 0 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 11 & -5 & -6 \\ -5 & 19 & -2 \\ -1 & -1 & 2 \end{vmatrix} = \begin{matrix} - & & + \\ - & & + \\ - & & + \end{matrix}$$

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

$$\Delta_1 = \begin{vmatrix} 12 & -5 & -6 \\ 0 & 19 & -2 \\ 0 & -1 & 2 \end{vmatrix} = \begin{matrix} - & & + \\ - & & + \\ - & & + \end{matrix} = 456 - 24 = 432$$

$$\Delta_2 = \begin{vmatrix} 11 & 12 & -6 \\ -5 & 0 & -2 \\ -1 & 0 & 2 \end{vmatrix} = \begin{matrix} - & & + \\ - & & + \\ - & & + \end{matrix} = 24 + 120 = 144$$

$$\Delta_3 = \begin{vmatrix} 11 & -5 & 12 \\ -5 & 19 & 0 \\ -1 & -1 & 0 \end{vmatrix} = \begin{matrix} - & & + \\ - & & + \\ - & & + \end{matrix} = 60 + 228 = 288$$

# Solution

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

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

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

# Mesh Analysis with Current Sources

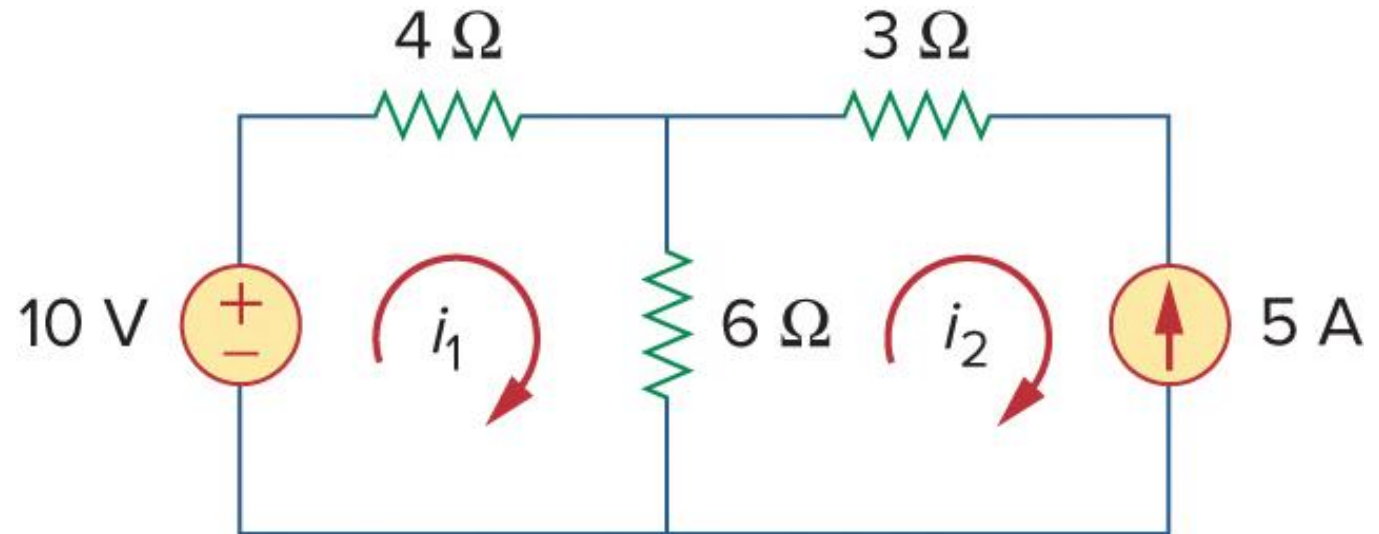
- How current sources affect mesh analysis. There are two cases.
- **Case I:** when a current source exists only in one mesh
- Set  $i_1 = -5 \text{ A}$
- Write mesh equation for the other mesh

KVL for mesh 1:

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

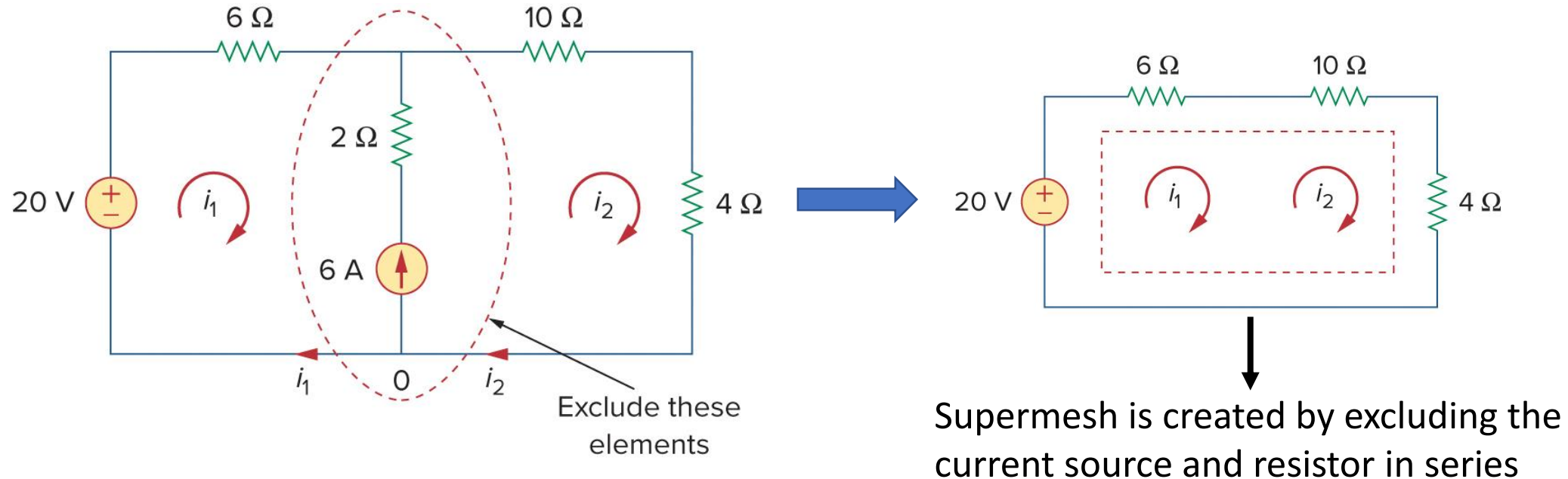
$$-10 + 4i_1 + 6i_1 - 6i_2 = 0$$

$$10i_1 - 6i_2 = 10 \Rightarrow i_1 = -2 \text{ A}$$



# Mesh Analysis with Current Sources

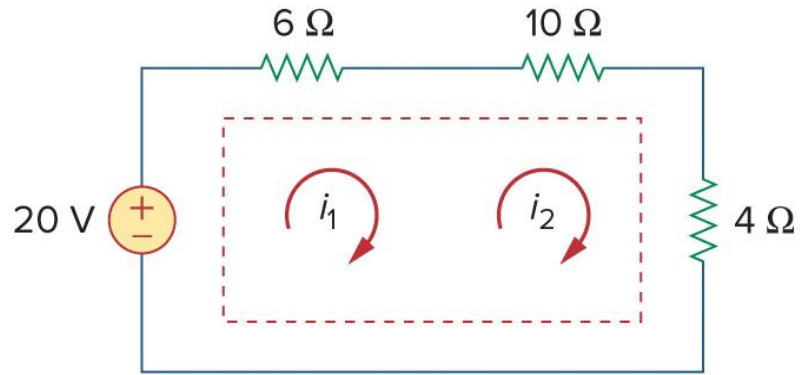
- **Case II:** When a current source exists between two meshes, create a **supermesh** by excluding the current source and any elements connected in series with it



- Supermesh 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

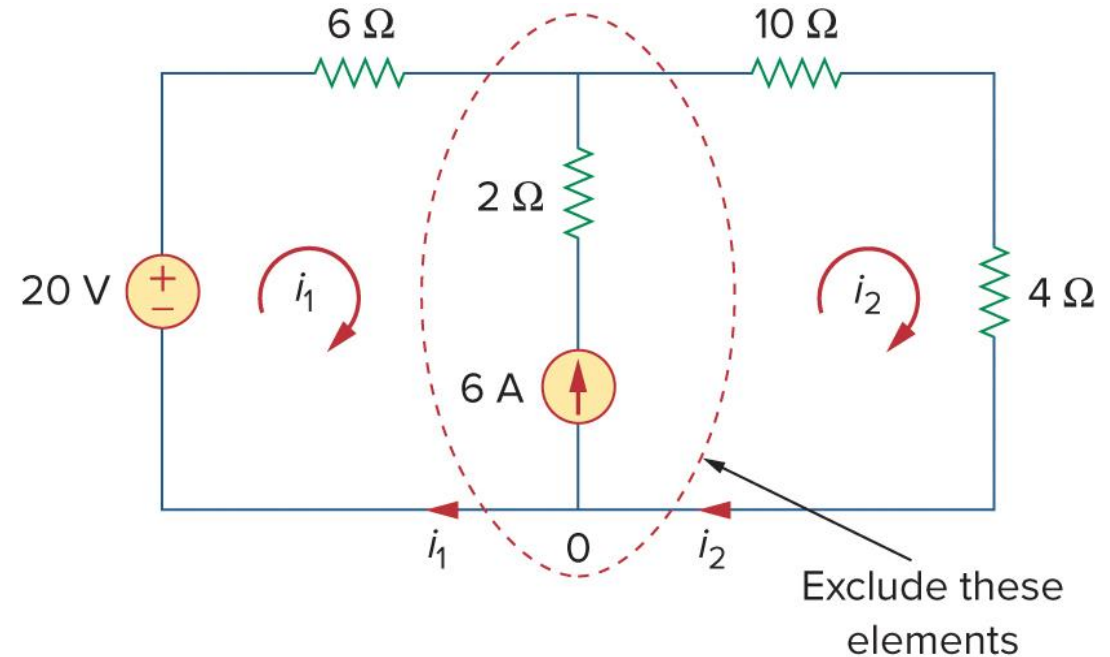
- A Supermesh requires the application of both KVL and KCL



- 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):

$$i_2 = i_1 + 6$$

$$i_1 = -3.2 \text{ A}, \quad i_2 = 2.8 \text{ A}$$



# Example 9

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

## Solution:

- Two supermeshes:
  - 1<sup>st</sup> one is between mesh 1 & 2
  - 2<sup>nd</sup> one is between mesh 2 & 3

- Combine them and exclude both current sources

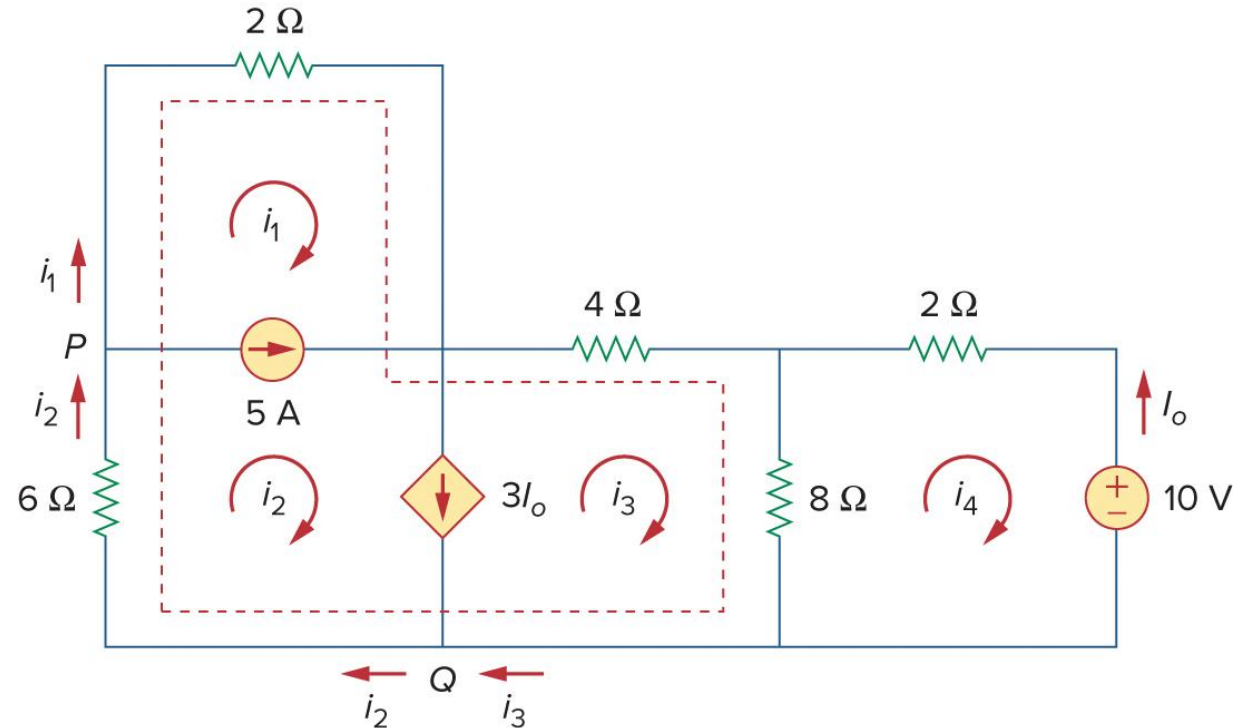
- Apply KVL to the larger supermesh:

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

$$i_1 + 3i_2 + 6i_3 - 4i_4 = 0 \rightarrow \text{Eq 1}$$

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

$$i_2 = i_1 + 5 \rightarrow \text{Eq 2}$$



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

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

$$i_2 = i_3 - 3i_4 \rightarrow \text{Eq 3}$$

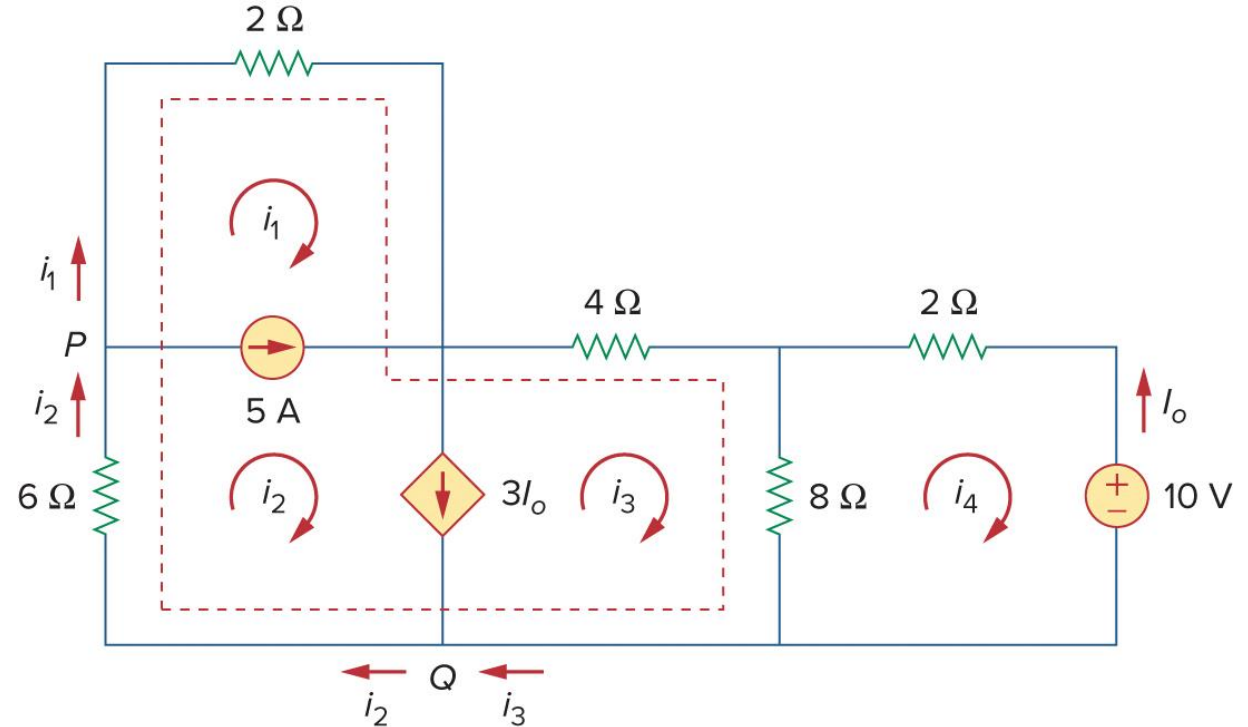
# Solution

- Apply KVL in mesh 4:

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

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

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



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

# Nodal versus Mesh Analysis

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- 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

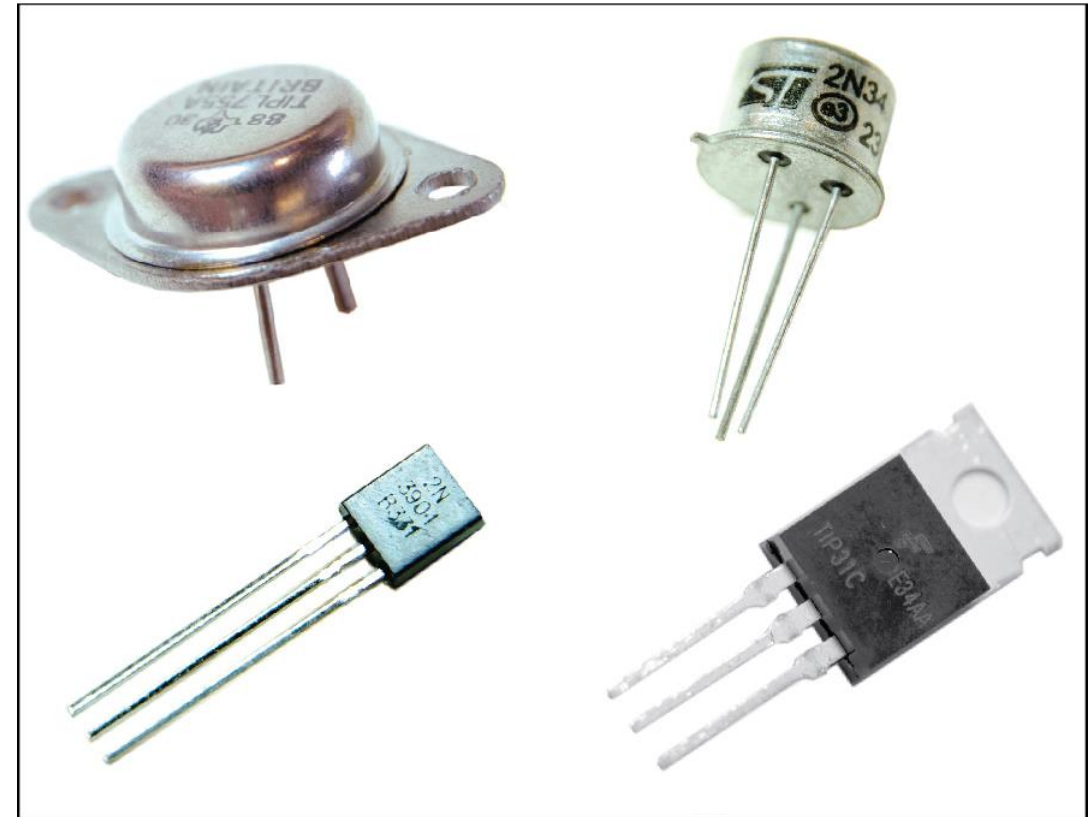
- Transistors play essential role for the design of integrated circuits (IC).

- 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)

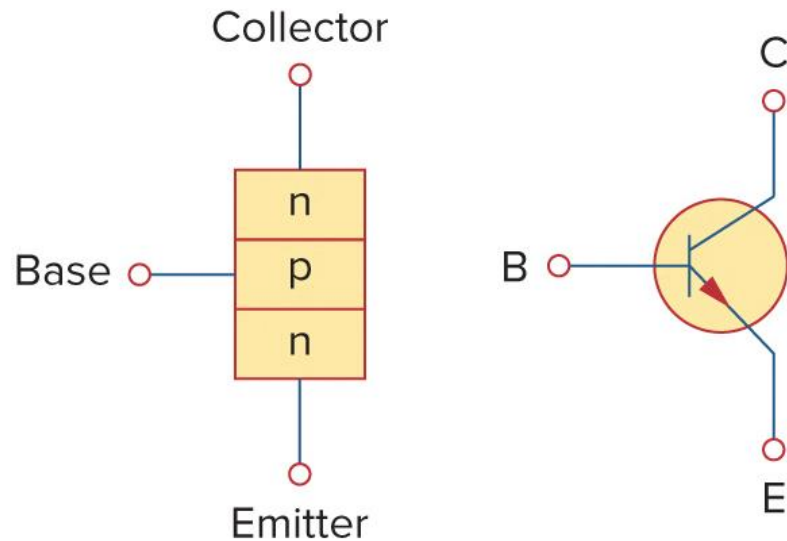


Various types of transistors

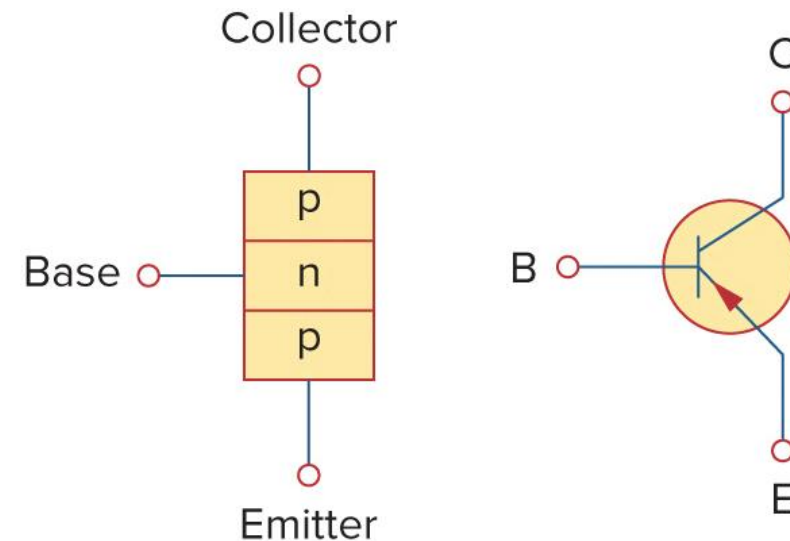
# DC Transistor Circuits

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

npn: Arrowhead pointing down

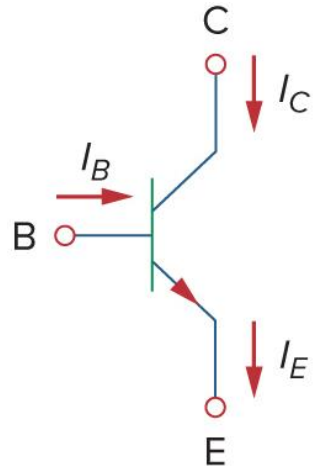


pnp: Arrowhead pointing up



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

# DC Transistor Circuits



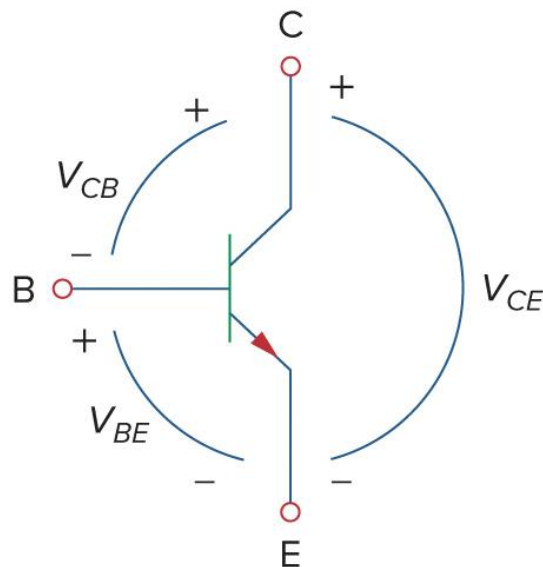
Apply KCL:  $\sum i_{in} = \sum i_{out}$

$$I_E = I_C + I_B$$

$I_E$ : 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:

$$V_{BE} \approx 0.7 \text{ V}$$

$$I_C = \alpha I_E$$

$$I_C = \beta I_B$$

$$I_E = I_C + I_B \Rightarrow I_E = \beta I_B + I_B \Rightarrow (1 + \beta) I_B \Rightarrow I_E = (1 + \beta) I_B$$

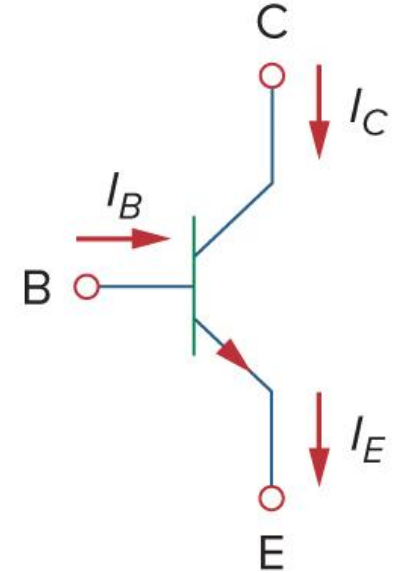
$$\alpha I_E = \beta I_B \Rightarrow \alpha \frac{I_E}{I_B} = \beta \Rightarrow \alpha \frac{(1 + \beta) I_B}{I_B} = \beta \Rightarrow \alpha + \alpha \beta = \beta$$

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

$\alpha$  : common-base current gain (in the range of 0.98 to 0.999)

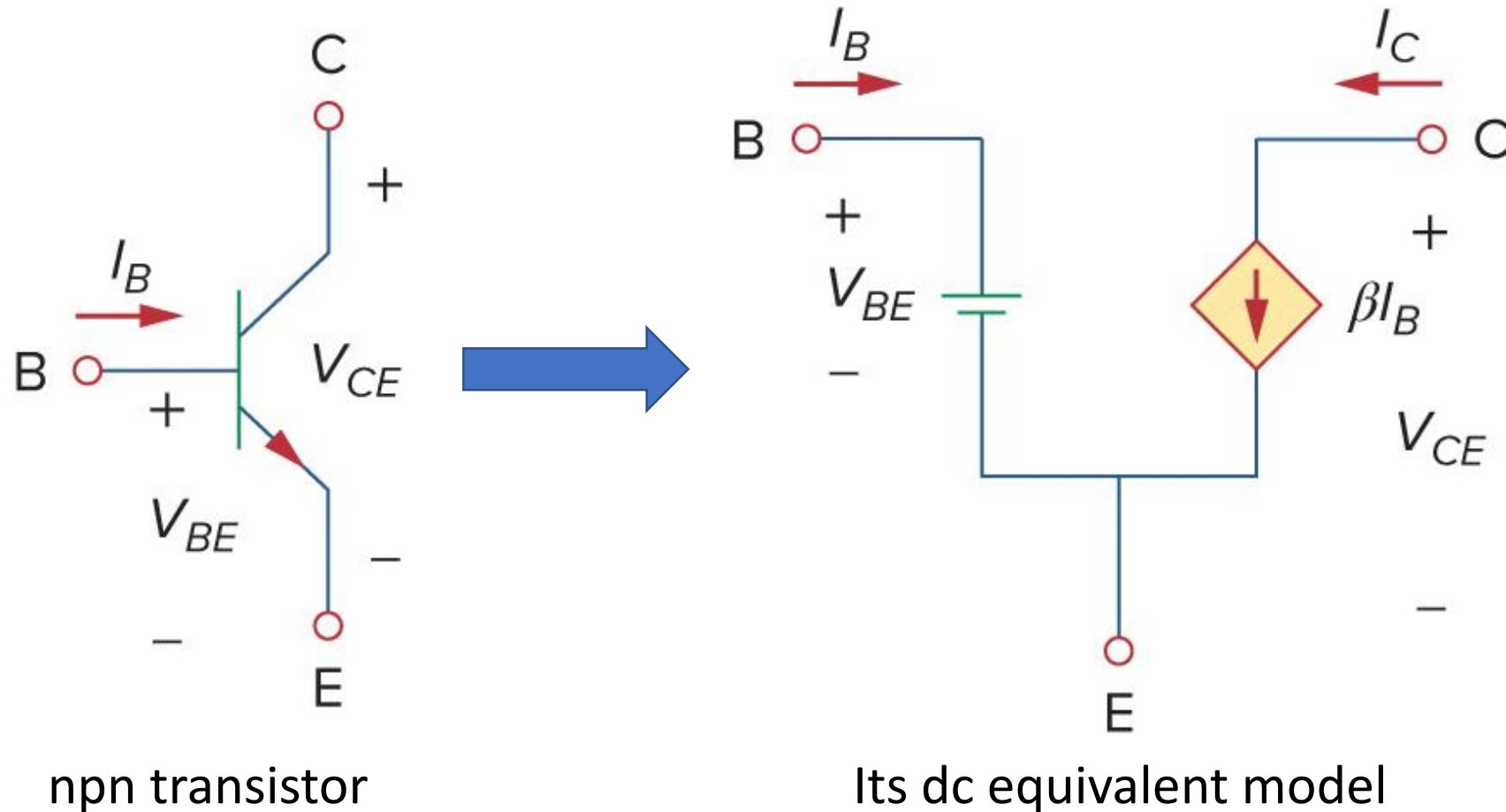
$\beta$  : common-emitter current gain (in the range of 50 to 1000)

$\alpha$  and  $\beta$  is the transistor properties and assume constant



# DC Transistor Circuits

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





## Example 10

Find the  $I_B$ ,  $I_C$ , and  $v_o$  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,

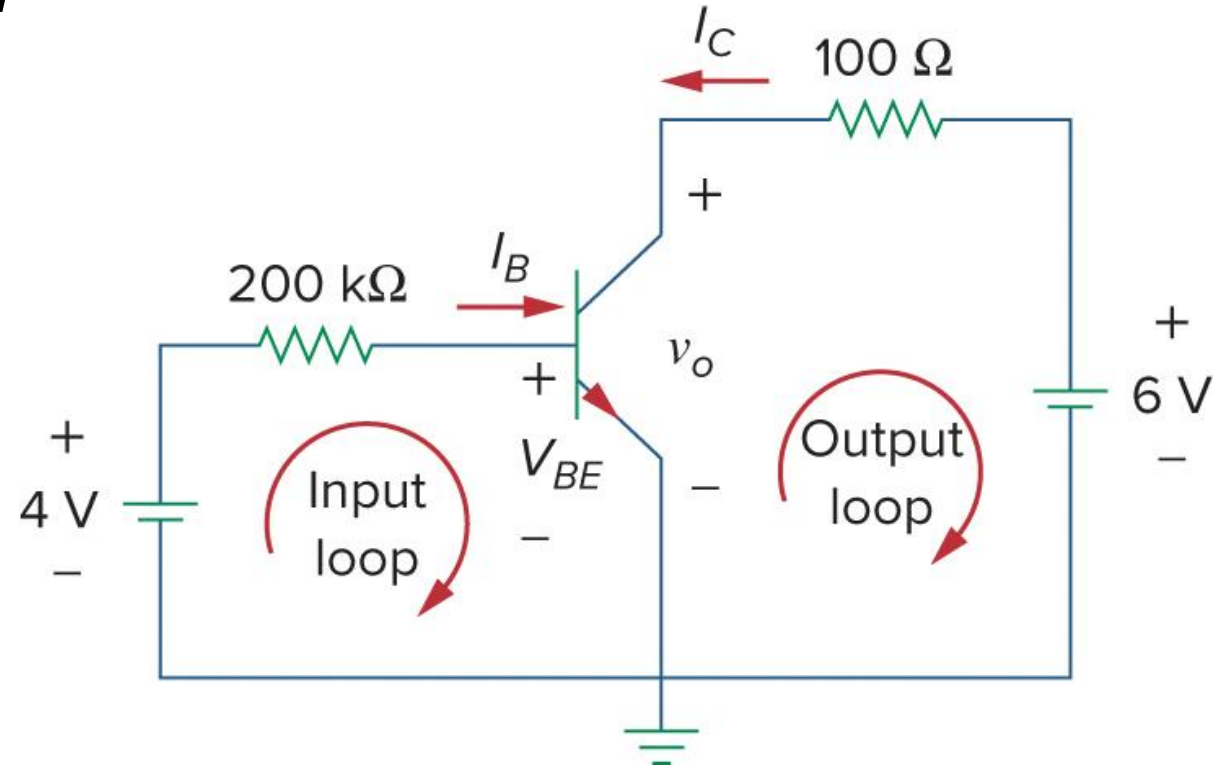
$$I_B = \frac{4 - 0.7}{20 \times 10^3} = 165 \mu\text{A}$$

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

For the output loop, KVL gives

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

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



# Example 11

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

## Solution:

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

1<sup>st</sup> loop:

$$-2 + 100kI_1 + 200k(I_1 - I_2) = 0$$

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

2<sup>nd</sup> loop:

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

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

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

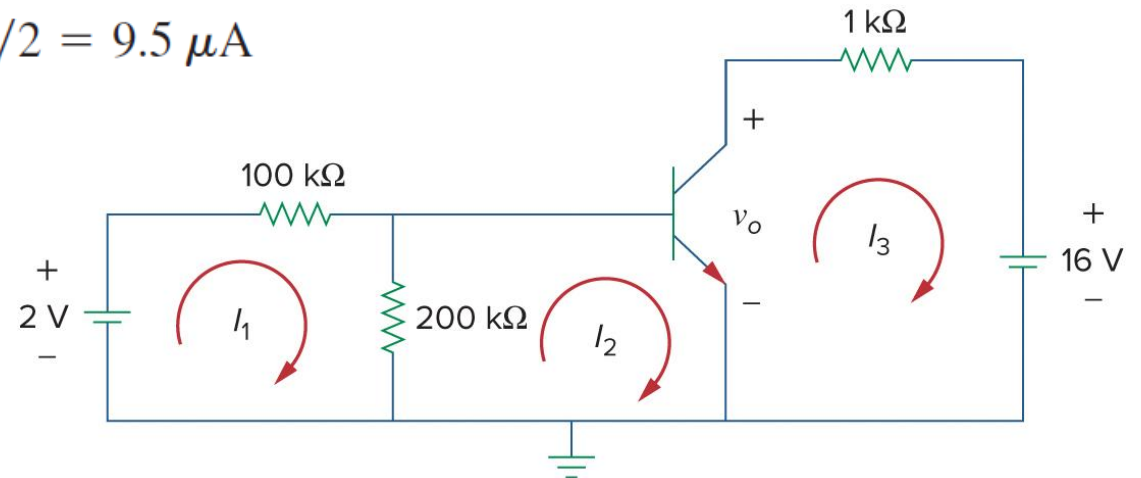
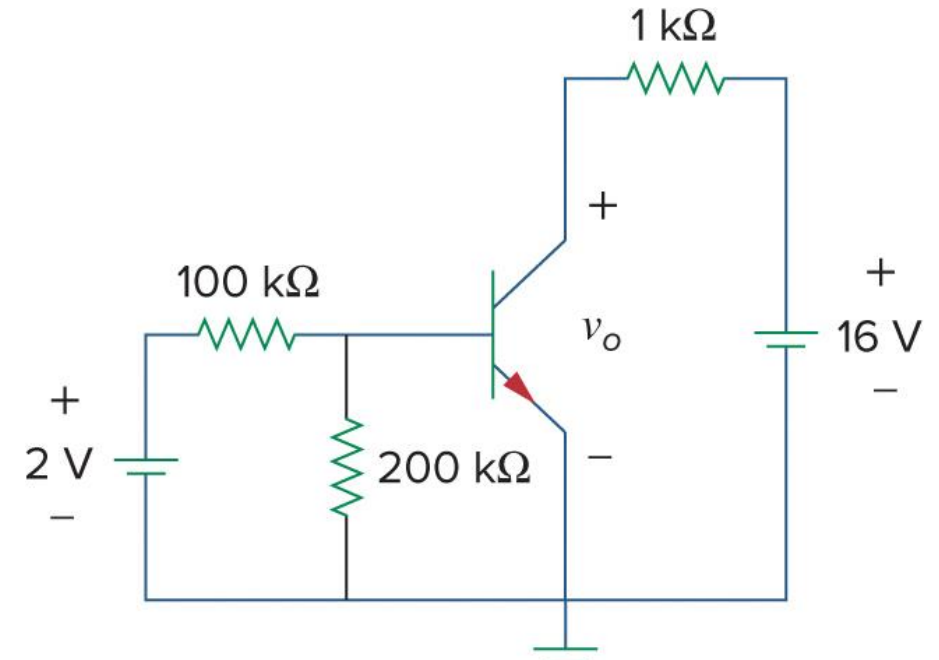
$$\text{Since } I_3 = -150I_2 = -1.425 \text{ mA}$$

3<sup>rd</sup> loop:

$$-v_o + 1kI_3 + 16 = 0$$

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

2 equations and  
2 unknowns



# Solution

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

At node number 1:  $V_1 = 0.7 \text{ V}$

Apply KCL:

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

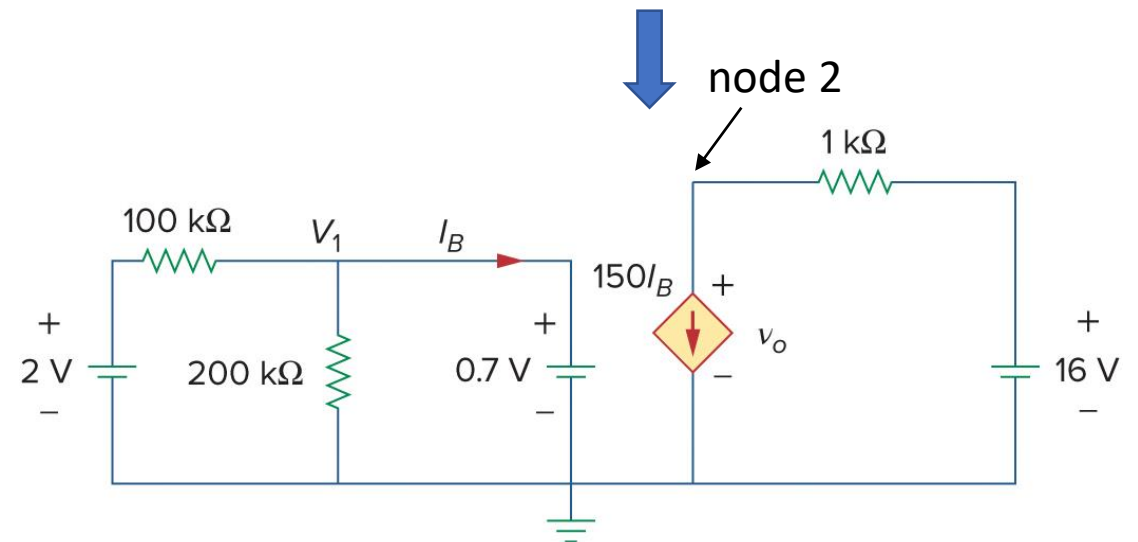
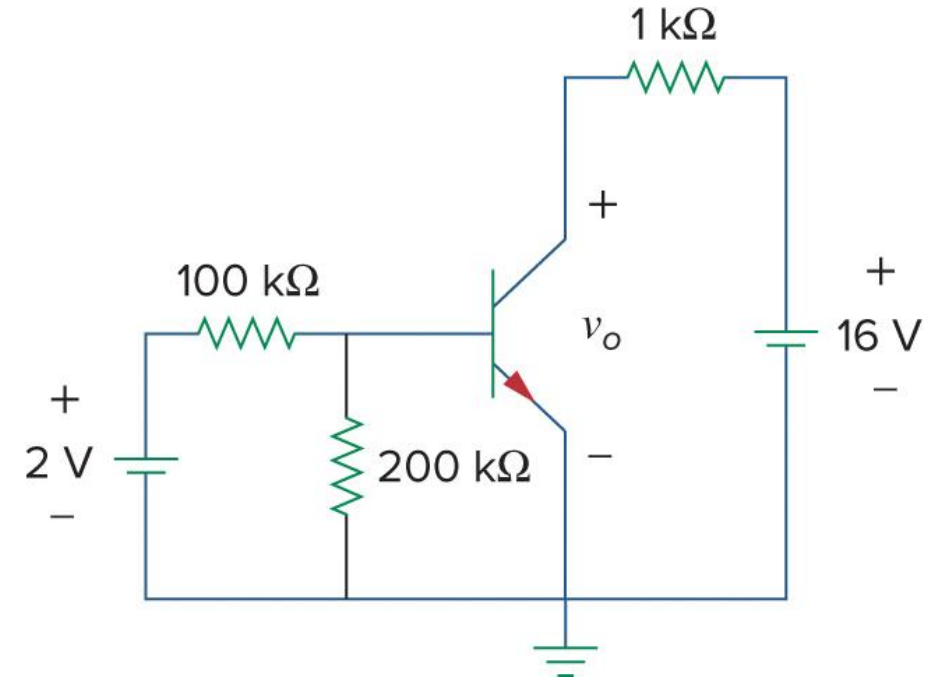
$$I_B = 9.5 \mu\text{A}$$

At node number 2 we have:

Apply KCL:

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

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



# 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

