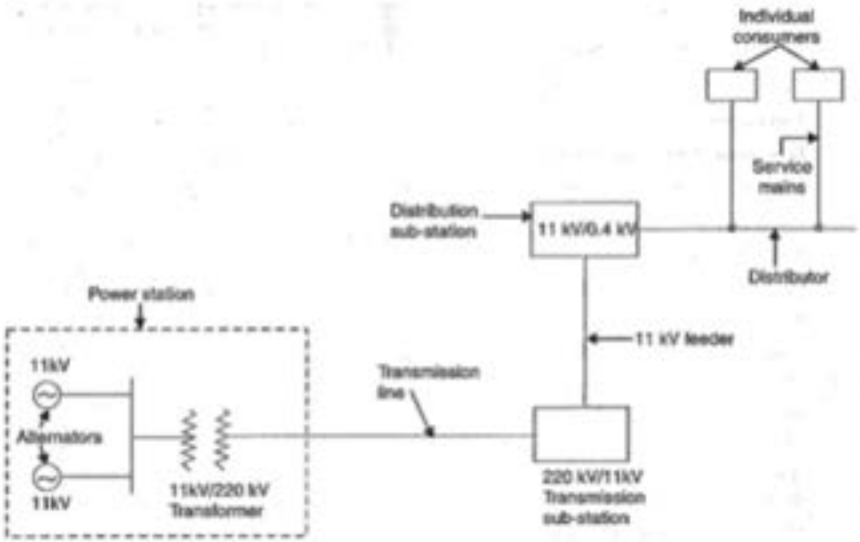
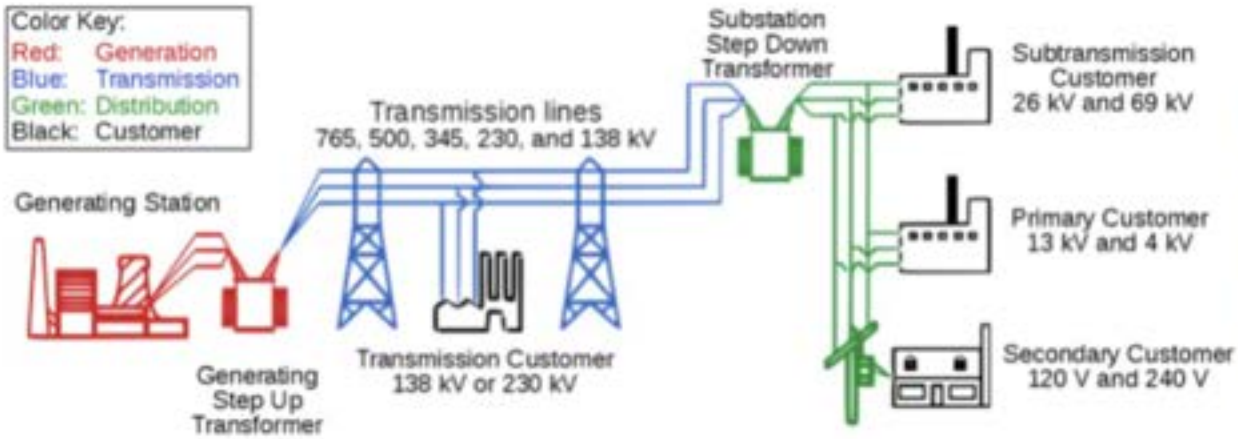
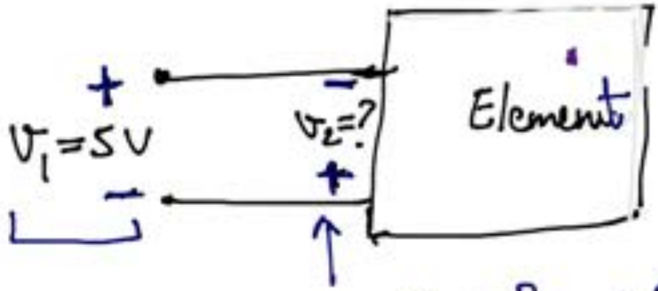
Electrical Substation



https://www.youtube.com/watch?v=I53NrBvlorQ



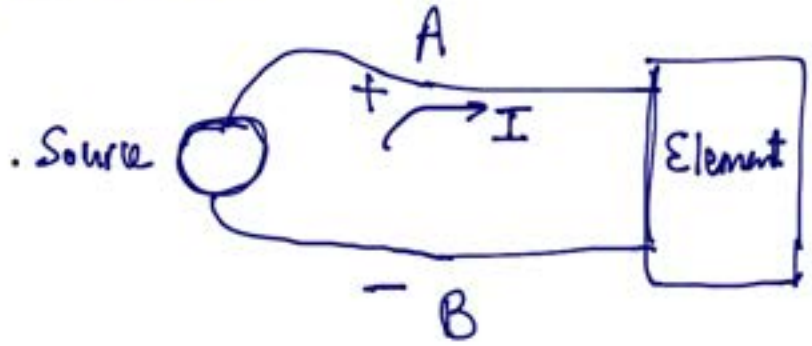
Lect 1: Chapter 2



$v_2 = ? = -5V$

$1V = 1\,J/C$

$1J = 1V * 1C$



Power Rate of work done

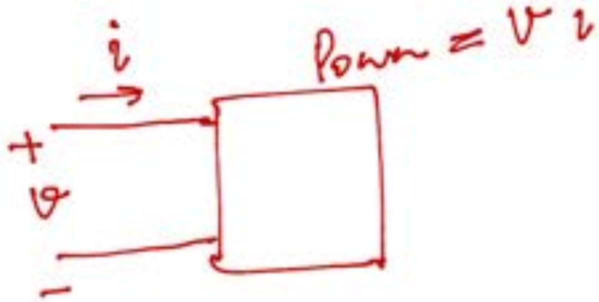
$1\,J \quad 1C \xrightarrow[1sec]{} \; : \; 1\,\text{Watts}$

$$\text{Power} = \frac{1V * 1C}{1\,sec} = 1V * \boxed{\frac{1C}{1sec}} = 1V * 1A$$

$$P = V * I$$

$$p(t) = v(t)\, i(t)$$

$$\boxed{p = vi}$$



−10W

−2×5
= −10W
(wrt B)

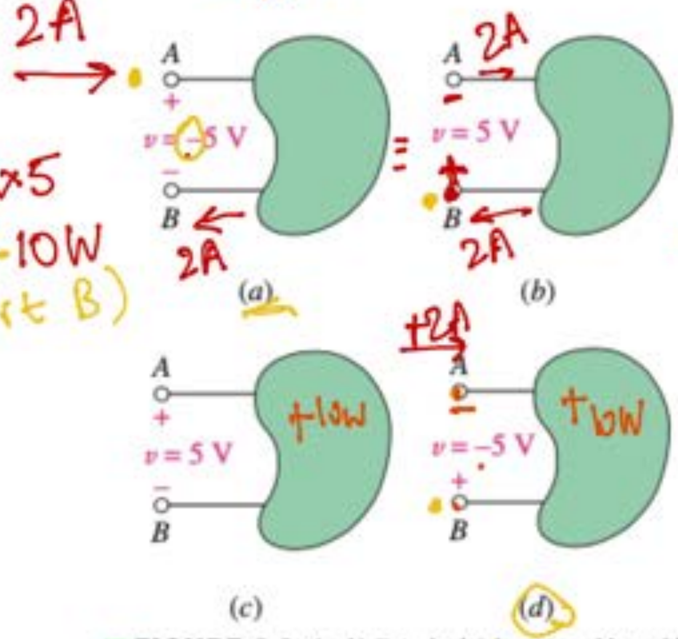
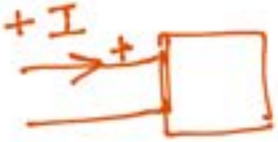


FIGURE 2.9 (*a*, *b*) Terminal *B* is 5 V positive with respect to terminal *A*; (*c*, *d*) terminal *A* is 5 V positive with respect to terminal *B*.

−10W

Look terminal B = 5V*(−2A)
= −10W



−5V*.(−2A)
= 10W
wrt

Compute the power absorbed by each part in Fig. 2.13.

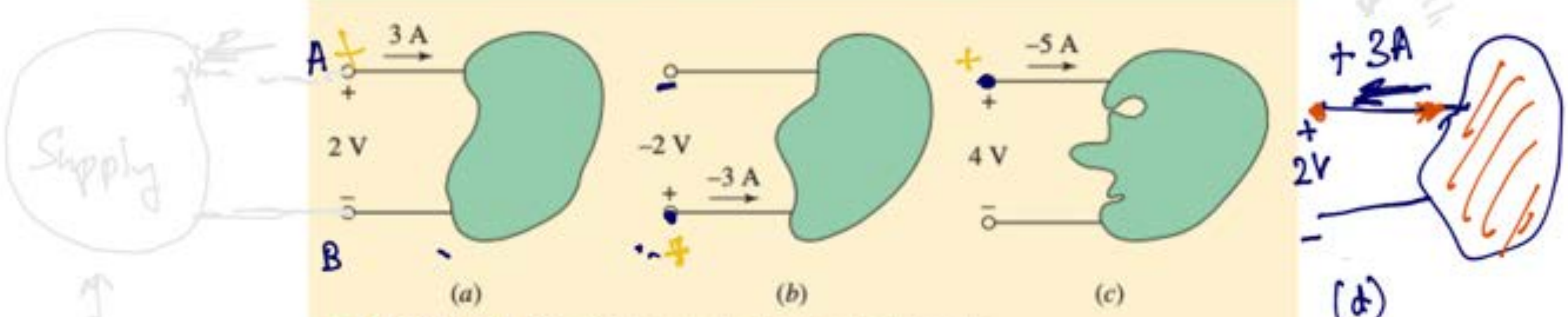
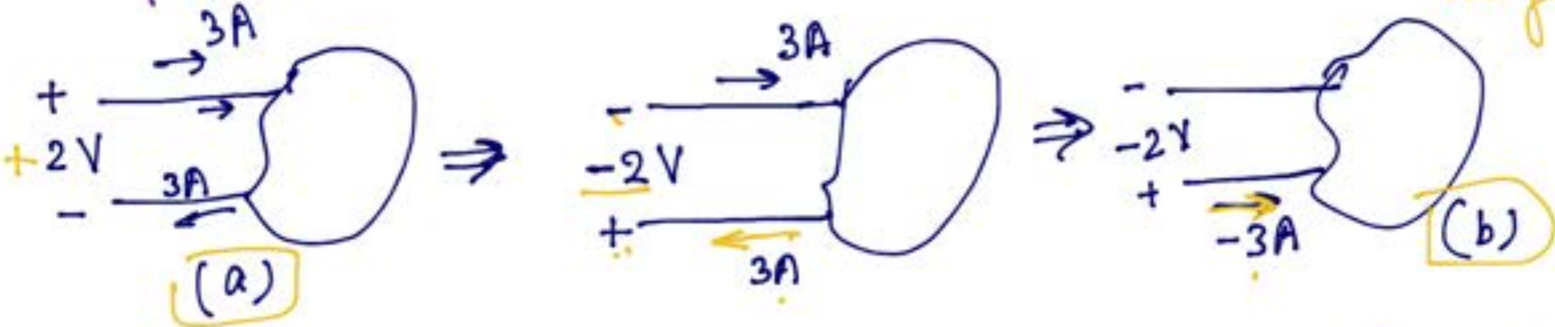


FIGURE 2.13 (*a, b, c*) Three examples of two-terminal elements.

(a) Power (wrt '+') = $V \times I$ = $2V * 3A = +6W$ ⇒ Absorbed

(b) Power (wrt '+') = $V \times I$ = $-2V * -3A = +6W$ Absorbed ↓ Using



(c) Power = $V \times I$ = $4V * (-5A) = -20W$ ↳ Supply

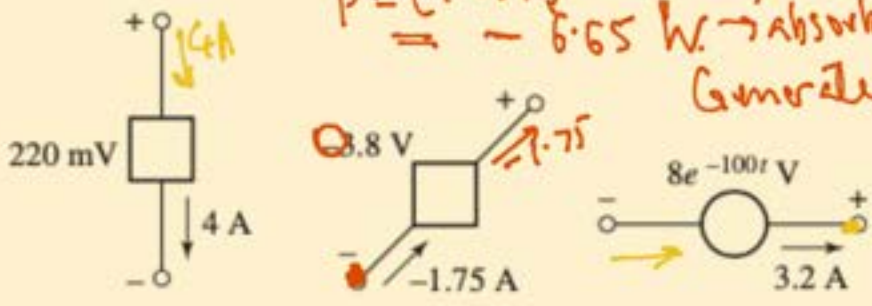
(d) Power = $V \times I$ = $2V * (-3A) = -6W$ Generating Source

2.6 Determine the power being absorbed by the circuit element in Fig. 2.14*a*.

$P = (1.75A) * (-3.8V)$

$= -6.65$ W → absorbed

Generated $= +6.65$W



(*a*) (*b*) (*c*)

FIGURE 2.14

$-3.2 * 8e^{-100t}$

$= -3.2 * 8 \left(e^{-.5}\right)$

2.7 Determine the power being generated by the circuit element in Fig. 2.14*b*.

2.8 Determine the power being delivered to the circuit element in Fig. 2.14*c* at $t = 5$ ms.

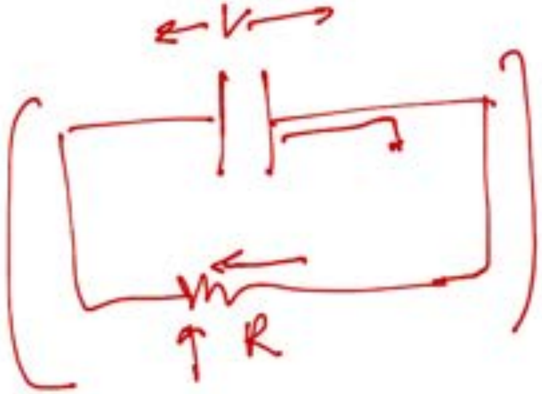
Sources → Independent — Voltage, Current; Dependent — voltage, current.

Circuit Element → ?

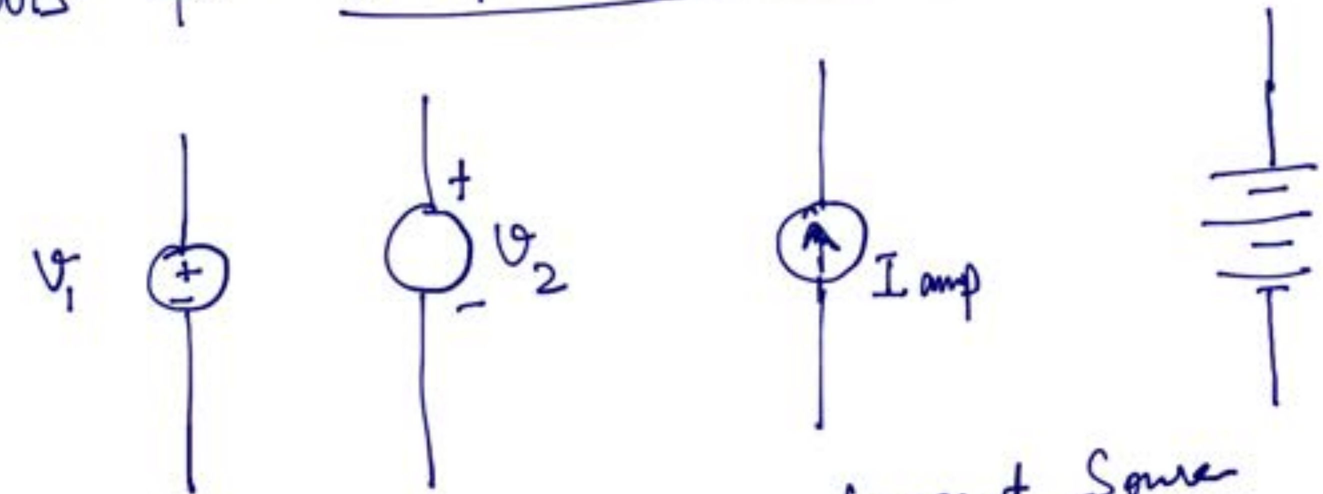
2 terminals

Mathematical Model

V − I relationship



Symbols for Independent Source



Current Source.

Voltage sources

Voltage Source : D.C source (constant); A.C (sinusoidal)


;

Dependent →

VCVS

'K v_x'

↓

voltage else where

Volt. dependent voltage source

CCVS

'r i_x'

↓

current else where

Current Dep Volt. source

VCCS

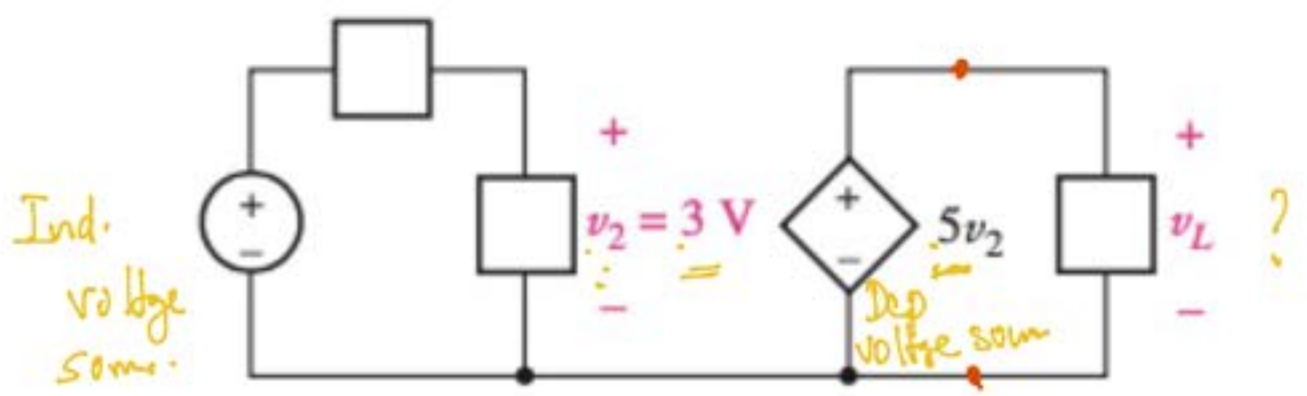
'g v_x'

Volt. dependent Current source

CCCS

'K i_x'

Current Dep. Current. Sou.



(*b*)

FIGURE 2.19 (*a*) An example circuit containing a voltage-controlled voltage source. (*b*) The additional information provided is included on the diagram.

Volt. dep volt. sour (VCVS) $= 5v_2$

$\downarrow$ controlled

$= 5 * 3$ V

$= \underline{15}$ V

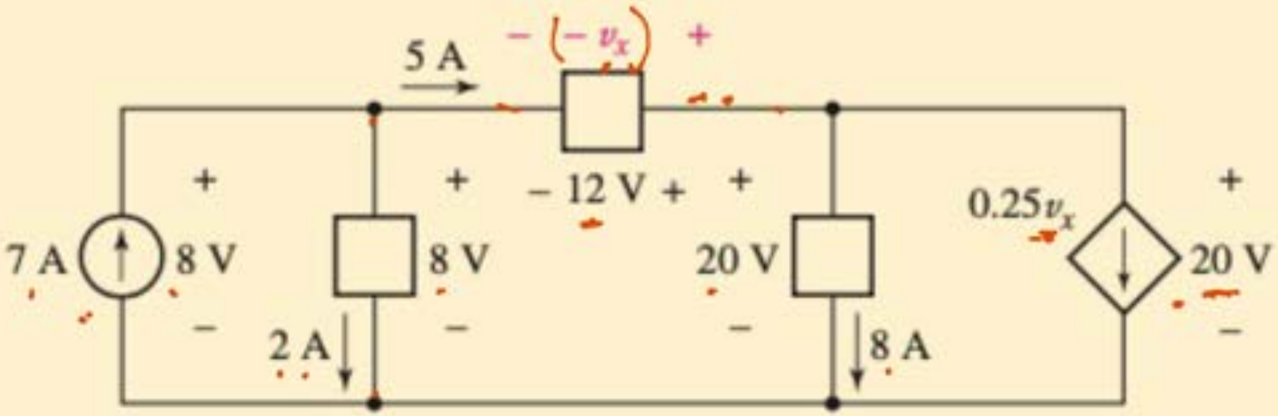
V_L = voltage supplied by VCVS.

$V_L = 15$V

PRACTICE

V, I

2.9 Find the power *absorbed* by each element in the circuit in Fig. 2.20.



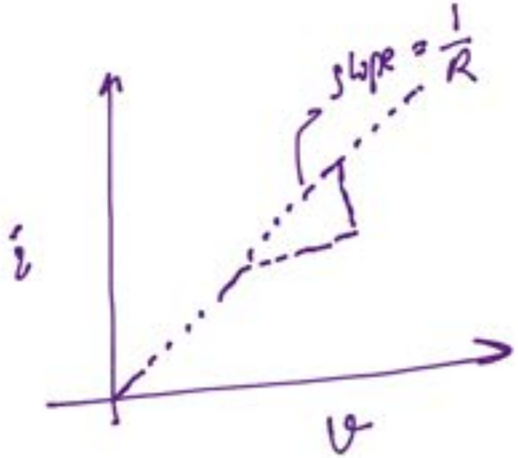
■ **FIGURE 2.20**

Ohm Law

$V \propto I$

$V = R . I$

Resistance. (Ω ohms)



Ohm's Law

$$V = I R$$ → Resistor

Power Absorption

$$P = v\,i \quad (v = iR,\ i = v/R)$$

$$= v^2/R = v^2 G$$ → conductance

$$= \underline{i^2 R}$$

R → Resistor (ohm $\Omega = V/A$)

Conductance

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

Unit: Siemens, A/V, $\mho$ (mho)
(S) ↓ $\mho$

CHAPTER 3
(lecture 2)

CHAPTER 3

VOLTAGE AND CURRENT LAWS 39

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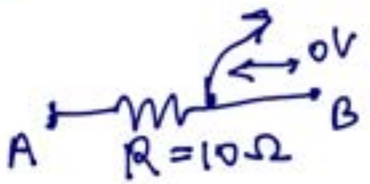
$\rightarrow$ $R = 0 \Rightarrow G = \infty \equiv$ Short Circuit

$R = \infty \Rightarrow G = 0 \equiv$ Open Circuit (no connection)

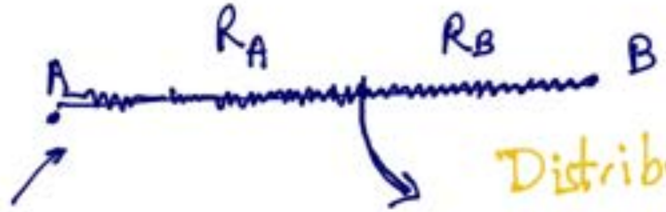
Voltage & Current Laws

Lumped parameter — Example: Resistor unit

Distributed parameter — Example: Transmission Line Capacitance.



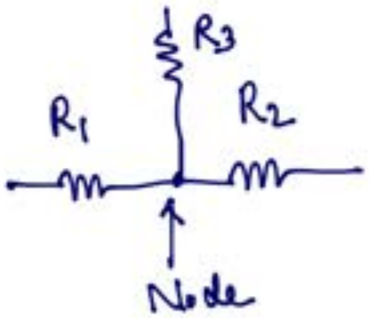
Lumped

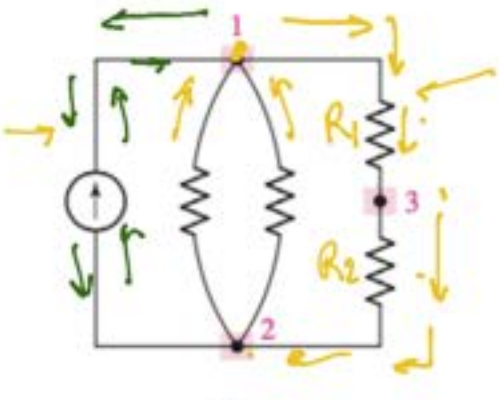


Distributed

Distributed

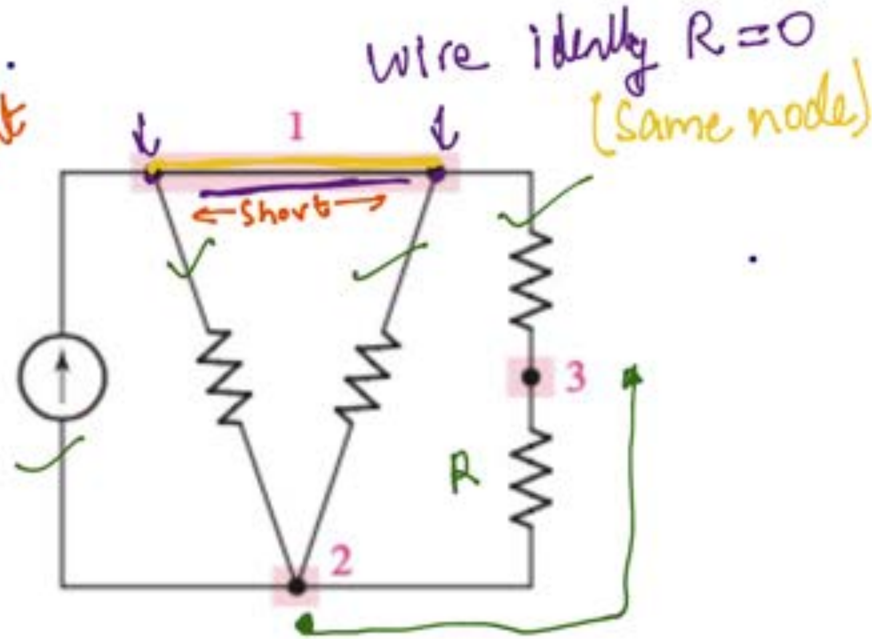
NODE : A point at which two or more elements have a common connection.





(a)

Same circuit



(b)

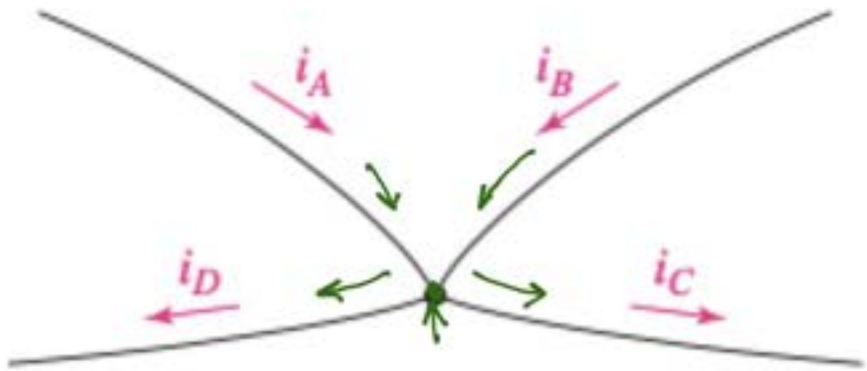
Path : $1 \to R_1 \to 3 \to R_2 \to 2$

Path When moving along in a circuit, set of nodes and elements encountered once form a path.

Loop A path will become a loop if end at same node at which we started.

Branch : A single path composed of a single element with a node at each end.

.



■ **FIGURE 3.2** Example node to illustrate the application of Kirchhoff's current law.

$$+ i_A + i_B - i_C - i_D = 0 \quad : \text{KCL}$$

KCL Kirchhoff's Current Law

Algebraic sum of currents entering any node is zero.

$$\sum_{n=1}^{N} i_n = 0$$

for a node with $\underline{\underline{N}}$ connections

$$\Downarrow$$

$$i_1 + i_2 + i_3 + \cdots \cdots + i_N = 0$$

KVL Kirchoff's Voltage Law

Sum of voltages around any closed path is zero.

$$\sum_{n=1}^{N} v_n = 0$$

In a closed loop with N elements (or branches).

$$v_1 + v_2 + v_3 + \cdots + v_N = 0$$

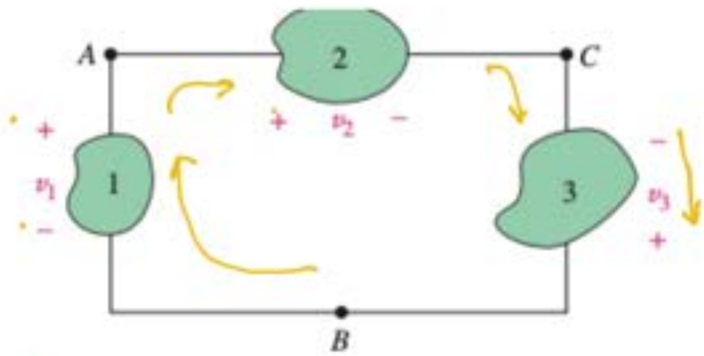
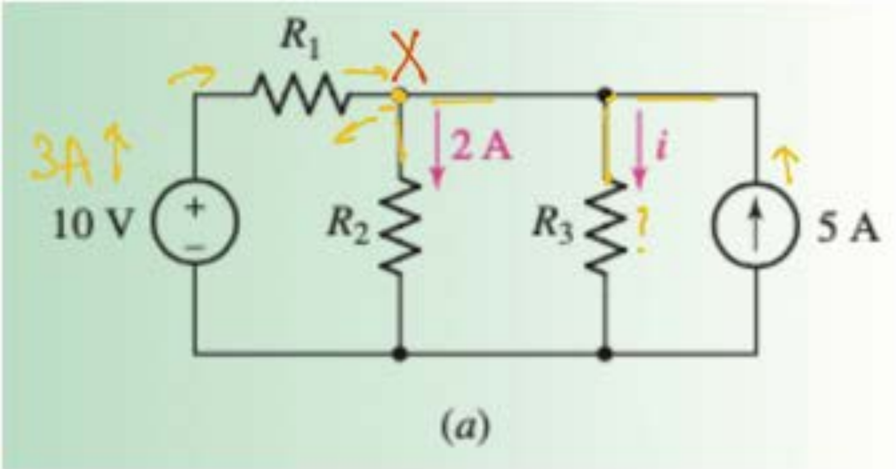


FIGURE 3.5 The potential difference between points *A* and *B* is independent of the path selected.

$$+v_1 - v_2 + v_3 = 0$$

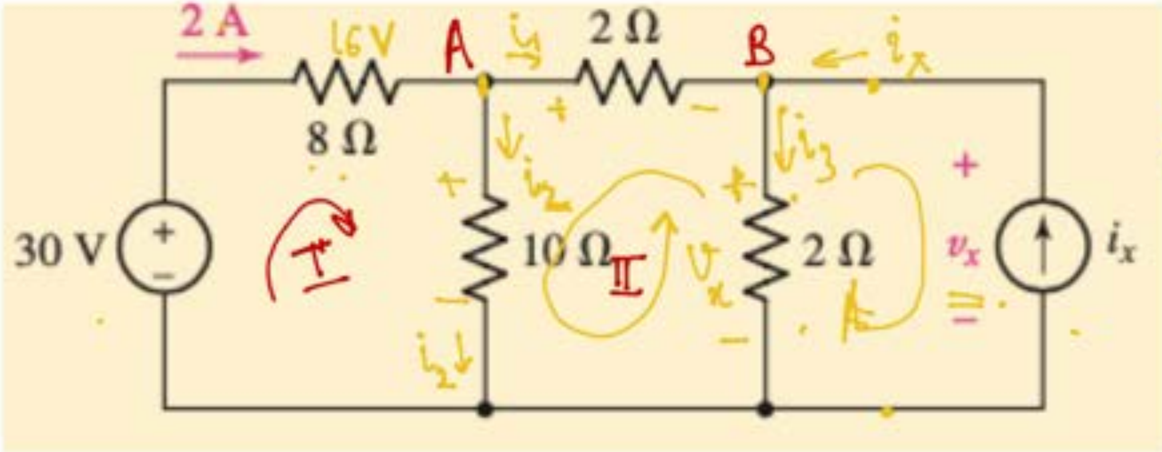


Ex 3.1

Apply KCL at node X : $3A - 2A - i + 5A = 0$

only one unknown

$\Rightarrow \quad i = 6A$



Ex 3.4

4 unknown & 4 equation.

KCL & KVL find the unknown.

$+30 - 8\times2 - 10\times i_2 = 0$: KVL@I → (4)

(KCL @ A) $i_1 + i_2 = 2A$ → (1)

(KCL @ B) $i_x + i_1 + \frac{\overset{i_3}{v_x}}{2A} = 0$ → (2)

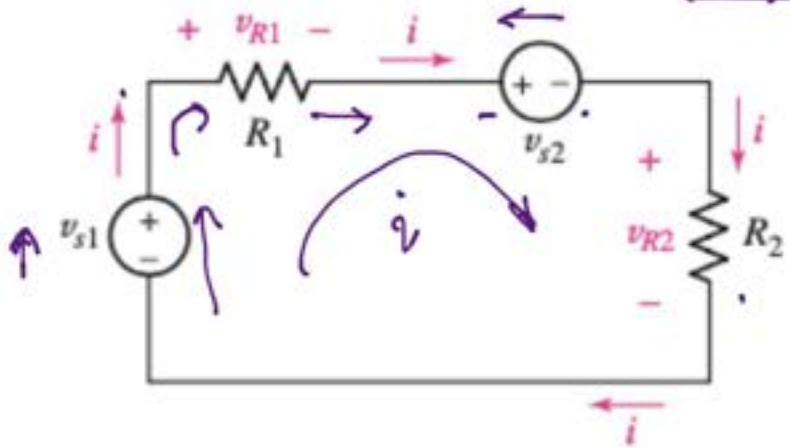
Unknowns i_1, i_2, i_x, i_3

(KVL @ loop II) : $-10 i_2 + v_x - 2 i_1 = 0$ → (3)

Ohm's Law (on 2Ω) : $v_x = 2\Omega (i_3) \Rightarrow i_x + i_1 = i_3$ → ~~(4)~~

Equation (2) (rewritten)

Single loop Circuit



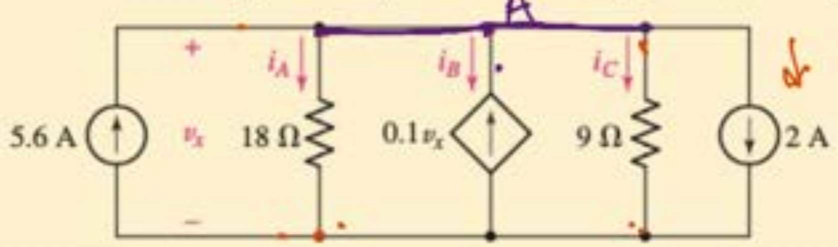
$$v_{R_1} = -iR_1$$

$$v_{R_2} = iR_2$$

$$+v_{s_1} - R_1 i_1 - v_{s2} - i_1 R_2 = 0 \quad \text{KVL}$$

$$i_1 = \frac{(v_{s_1} - v_{s2})}{(R_1 + R_2)}$$

3.8 For the single-node-pair circuit of Fig. 3.18, find i_A, i_B, and i_C.



Ex 3.8

$$i_A, i_B, i_C = ?$$

KCL (A)

$$+5.6A - i_A - i_B - i_C - 2A = 0 \quad \text{— (1)}$$

Total current A

Ohm's Law

$$\therefore i_B = -0.1\,v_x \quad \text{— (2)}$$

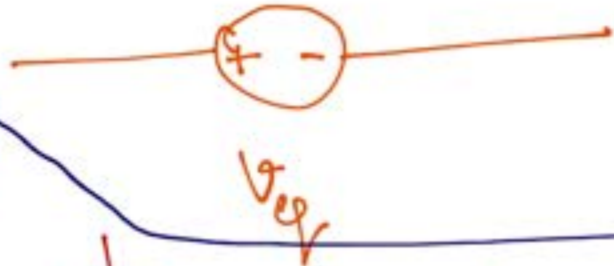
$$\therefore i_A = \frac{v_x}{18\,\Omega} \quad \text{— (3)} \; ; \quad i_C = \frac{v_x}{9\,\Omega} \quad \text{— (4)}$$

$$5.6 - \frac{v_x}{18} - (0.1)v_x - \frac{v_x}{9} - 2 = 0$$

Voltage Source

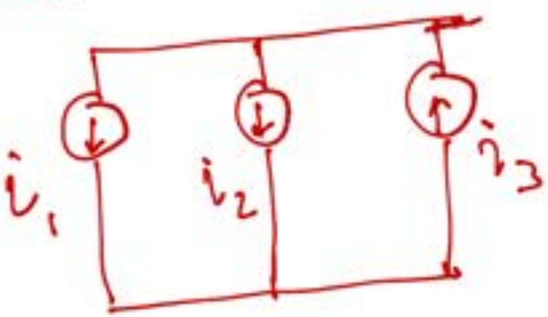
Series voltage source

$$v_{eq} = v_1 + v_2 - v_3$$



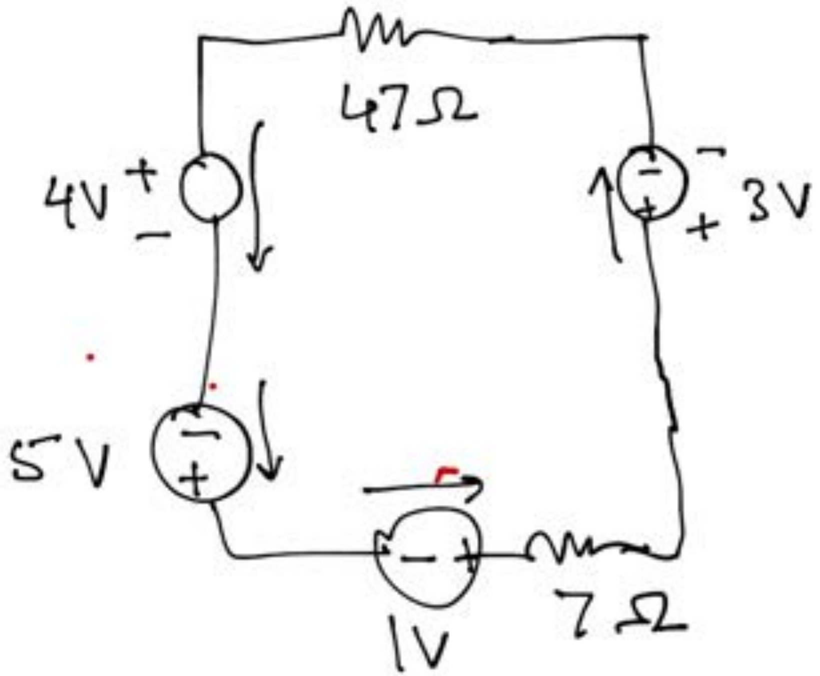
Equivalent Voltage Source

Parallel current Source



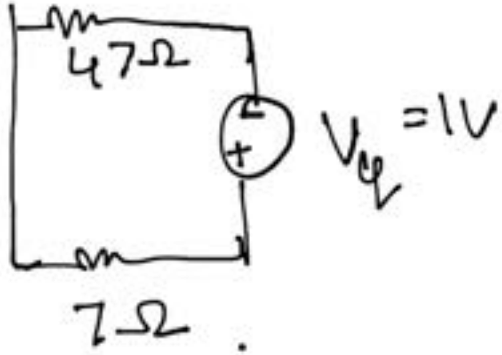
$$i_{eq} = i_1 + i_2 - i_3$$

3.9



$V_{eq} = +4-5-1+3$

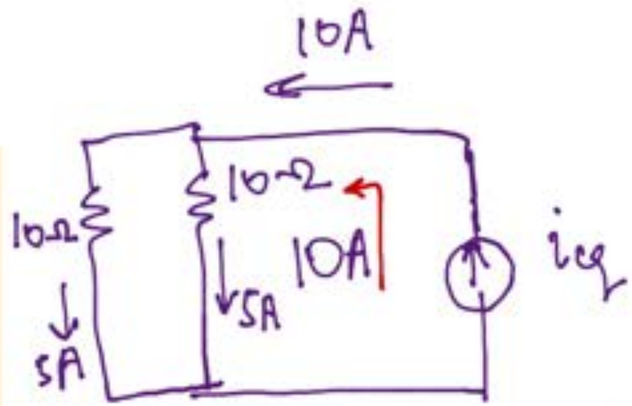
$V_{eq} = 1V$



3.10

3.10 Determine the voltage v in the circuit of Fig. 3.23 after first replacing the three sources with a single equivalent source.

FIGURE 3.23



$v = 5A \times 10\Omega = 50V$

10A will split equally between two equal resistors (10Ω & 10Ω) = 5A through each resistor.

Voltage Division in Series Resistance

i

$$v_1 = i R_1$$

$$v_2 = i R_2$$

$$i = \left\{\frac{v_1}{R_1}\right\} = \frac{v_2}{R_2} \cdots = \left\{\frac{v_N}{R_N}\right\}$$

⇒ Higher resistance will have higher voltage drop

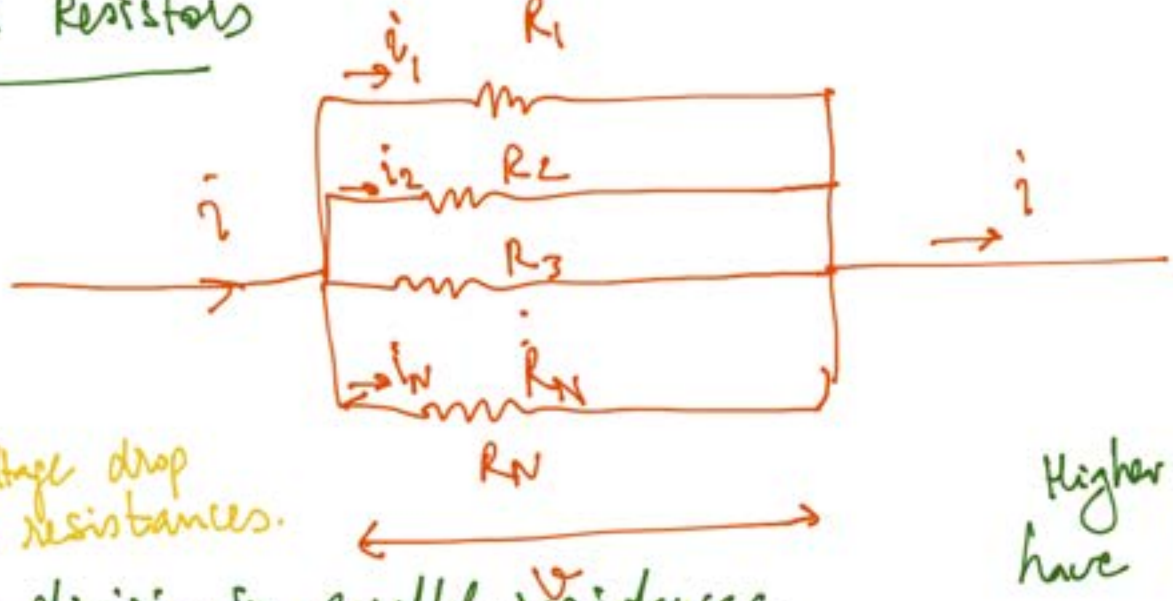
$$v_2 = \frac{R_2}{R_1 + R_2 + \cdots R_N} * v$$

Voltage Division Based on Resistance

⇓

Resistor Voltage Divider

Parallel Resistors

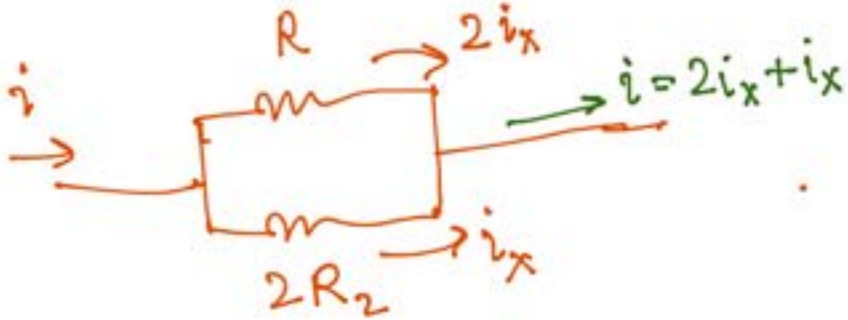


Same voltage drop across all resistances.

Higher resistance will have lower current.

Current division in parallel resistances.

$$v = i_1 \cdot R_1 = i_2 R_2 = \cdots = i_N R_N$$



CHAPTER 4

CHAPTER 4

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4.4 The Supermesh 98

4.5 Nodal vs. Mesh Analysis: A Comparison 101

4.6 Computer-Aided Circuit Analysis 103

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P

4.1 For the circuit of Fig. 4.3, determine the nodal voltages v_1 and v_2.

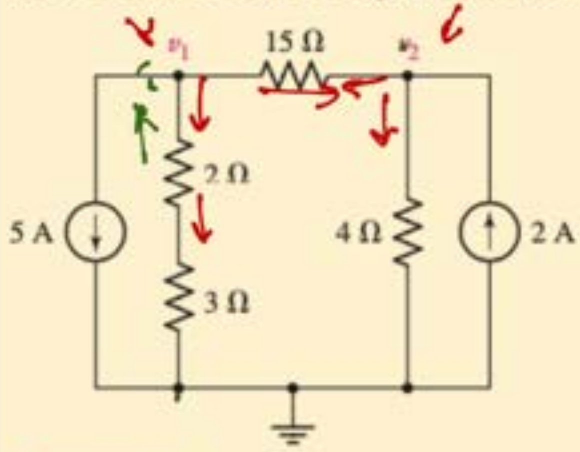


FIGURE 4.3

$$4v_1 - 19v_2 + 120 = 0$$

$v_1 - v_2$ = current flowing from higher to lower node

$\xrightarrow[i]{}$

KCL @ v_1

$$-5 - \frac{v_1 - 0}{2+3} - \frac{v_1 - v_2}{15\Omega} = 0$$

$$-5 - \frac{v_1}{5} - \frac{v_1}{15} + \frac{v_2}{15} = -75 - 3v_1 - v_1 + v_2 = 0$$

$$= -4v_1 + v_2 - 75 = 0 \quad (1)$$

KCL @ v_2

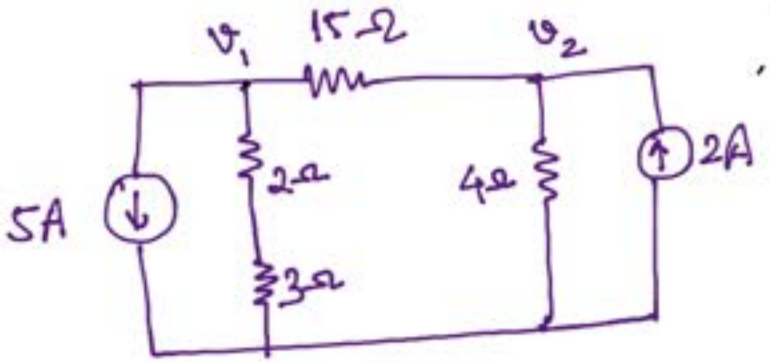
$$+\frac{v_1 - v_2}{15} - \frac{v_2}{4} + 2 = 0$$

$$4v_1 - 4v_2 - 15v_2 + 120 = 0$$

$$4v_1 - 19v_2 + 120 = 0 \quad (2)$$

Ex 4.1

(Solved for reference)



$v_1, v_2 = ?$

Node v_1 KCL: $-5 - \frac{v_1}{5} - \frac{v_1 - v_2}{15} = 0$

$$\Rightarrow \quad +75 + 3v_1 + v_1 - v_2 = 0$$

$$\Rightarrow \quad 4v_1 - v_2 + 75 = 0 \quad \text{------} \quad (1)$$

Node v_2 KCL $\quad -\frac{v_2 - v_1}{15} + 2 - \frac{v_2}{4} = 0$

$$\Rightarrow \quad -4v_2 + 4v_1 + 120 - 15v_2 = 0 \longleftarrow (2)$$

$$\Rightarrow \quad 4v_1 - 19v_2 + 120 = 0$$

$(1) - (2) \Rightarrow \quad 18v_2 = 45 \Rightarrow \boxed{v_2 = 5/2 \text{ V}}$

$(1) \Rightarrow \quad v_1 = \frac{1}{4}\left(-75 + \frac{5}{2}\right) = \frac{1}{4}\left(\frac{-145}{2}\right) = \boxed{-\frac{145}{8} \text{ V}}$

P 4.2

PRACTICE

4.2 For the circuit of Fig. 4.5, compute the voltage across each current source.

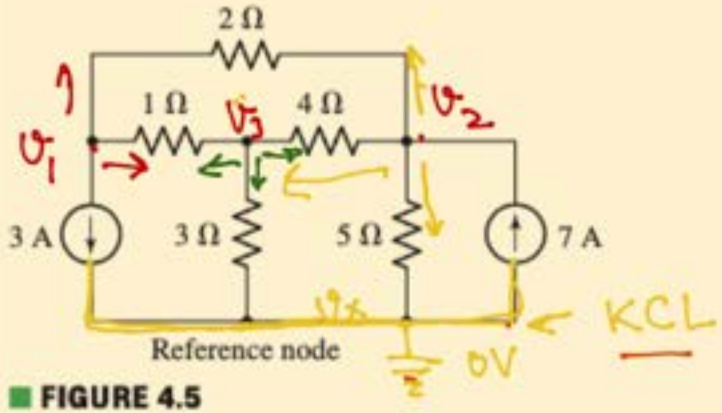


FIGURE 4.5

Ideal wire
R=0

KCL @ v_1 $\quad \frac{v_1 - v_2}{2} + \frac{v_1 - v_3}{1} + 3 = 0 \Rightarrow v_1 - v_2 + 2v_1 - 2v_3 + 6$

$v_1 = A$ volt $\quad \underbrace{v_1 - \text{ref.} = A}$ $\quad \Rightarrow 3v_1 - v_2 - 2v_3 + 6 = 0$ — (1)

KCL @ v_2 $\quad +\frac{v_2 - v_1}{2} + \left(\frac{v_2 - v_3}{4}\right) + \frac{v_2}{5} \mp 7 = 0$

$\Rightarrow -10v_2 + 10v_1 - 5v_2 + 5v_3 - 4v_2 + 140 = 0$

$\Rightarrow 10v_1 - 19v_2 + 5v_3 + 7 = 0$ — (2)

KCL @ v_3 $\quad \frac{v_3 - v_1}{1} + \frac{v_3}{3} + \left(\frac{v_3 - v_2}{4}\right) = 0$ — (3)

Determine the node-to-reference voltages in the circuit of Fig. 4.11.

After establishing a supernode about each *voltage* source, we see that we need to write KCL equations only at node 2 and at the supernode containing the dependent voltage source. By inspection, it is clear that $v_1 = -12$ V.

At node 2,

$$\frac{v_2 - v_1}{0.5} + \frac{v_2 - v_3}{2} = 14 \quad \text{— (1)} \qquad [20]$$

while at the 3-4 supernode,

$$\text{in} \quad 0.5v_x = \frac{v_3 - v_2}{2} + \frac{v_4}{1} + \frac{v_4 - v_1}{2.5} \quad \text{out} \quad \text{— (2)} \qquad [21]$$

We next relate the source voltages to the node voltages:

$$v_3 - v_4 = 0.2v_y \quad \text{— (3)} \qquad [22]$$

and

$$0.2v_y = 0.2(v_4 - v_1) \qquad [23]$$

Finally, we express the dependent current source in terms of the assigned variables:

$$0.5v_x = 0.5(v_2 - v_1) \quad \text{— (4)} \qquad [24]$$

Five nodes requires *four* KCL equations in general nodal analysis, but we have reduced this requirement to *only two,* as we formed two separate supernodes. Each supernode required a KVL equation (Eq. [22] and $v_1 = -12$, the latter written by inspection). Neither dependent source was controlled by a nodal voltage, so two additional equations were needed as a result.

With this done, we can now eliminate v_x and v_y to obtain a set of four equations in the four node voltages:

$$\begin{aligned}
-2v_1 + 2.5v_2 - 0.5v_3 \qquad\qquad &= 14 \\
0.1v_1 - v_2 + 0.5v_3 + 1.4v_4 &= 0 \\
v_1 \qquad\qquad\qquad\qquad &= -12 \\
0.2v_1 \qquad + v_3 - 1.2v_4 &= 0
\end{aligned}$$

Solving, $v_1 = -12$ V, $v_2 = -4$ V, $v_3 = 0$ V, and $v_4 = -2$ V.

Super Node

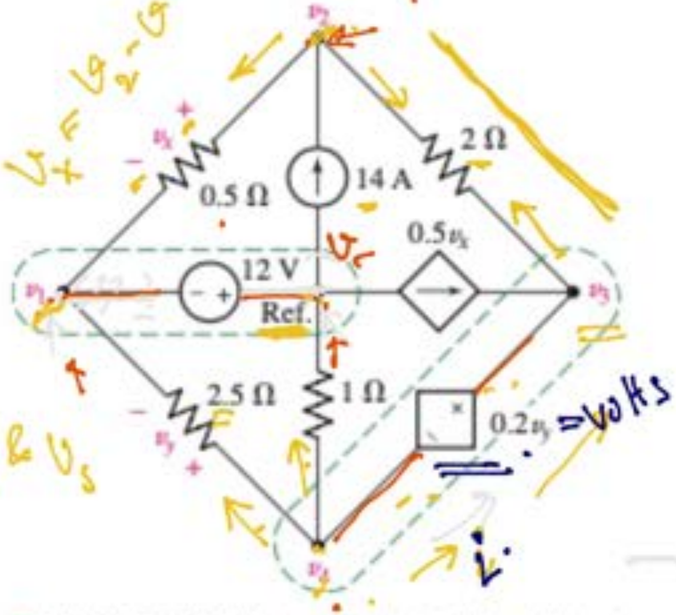


FIGURE 4.11 A five-node circuit with four different types of sources.

v_4: $\dfrac{v_4 - v_1}{2.5} + \dfrac{v_4 - 0}{1} + i = 0$

v_3: $-\dfrac{v_3 - v_2}{2} + 0.5v_x + i = 0$

$v_4 - v_3 \rightarrow$ Supernode

$$\frac{v_4 - v_1}{2.5} + \frac{v_4}{1} + \frac{v_3 - v_2}{2} - 0.5v_x = 0$$

Summary of Supernode Analysis Procedure

1. **Count the number of nodes** (N).
2. **Designate a reference node.** The number of terms in your nodal equations can be minimized by selecting the node with the greatest number of branches connected to it.
3. **Label the nodal voltages** (there are $N - 1$ of them).
4. **If the circuit contains voltage sources, form a supernode about each one.** This is done by enclosing the source, its two terminals, and any other elements connected between the two terminals within a broken-line enclosure.
5. **Write a KCL equation for each nonreference node and for each supernode *that does not contain the reference node*.** Sum the currents flowing *into* a node/supernode from current sources on one side of the equation. On the other side, sum the currents flowing *out* of the node/supernode through resistors. Pay close attention to "−" signs.
6. **Relate the voltage across each voltage source to nodal voltages.** This is accomplished by simple application of KVL; one such equation is needed for each supernode defined.
7. **Express any additional unknowns (i.e., currents or voltages other than nodal voltages) in terms of appropriate nodal voltages.** This situation can occur if dependent sources appear in our circuit.
8. **Organize the equations.** Group terms according to nodal voltages.
9. **Solve the system of equations for the nodal voltages** (there will be $N - 1$ of them).

N KCL

(N−1) No y^n = ref. node

KCL (N−1)

Super $\underbrace{A \& B}$ → Voltage Sour

$V_A - V_B = V_{source}$

KVL

Planar circuit →

Mesh → no loop inside it.

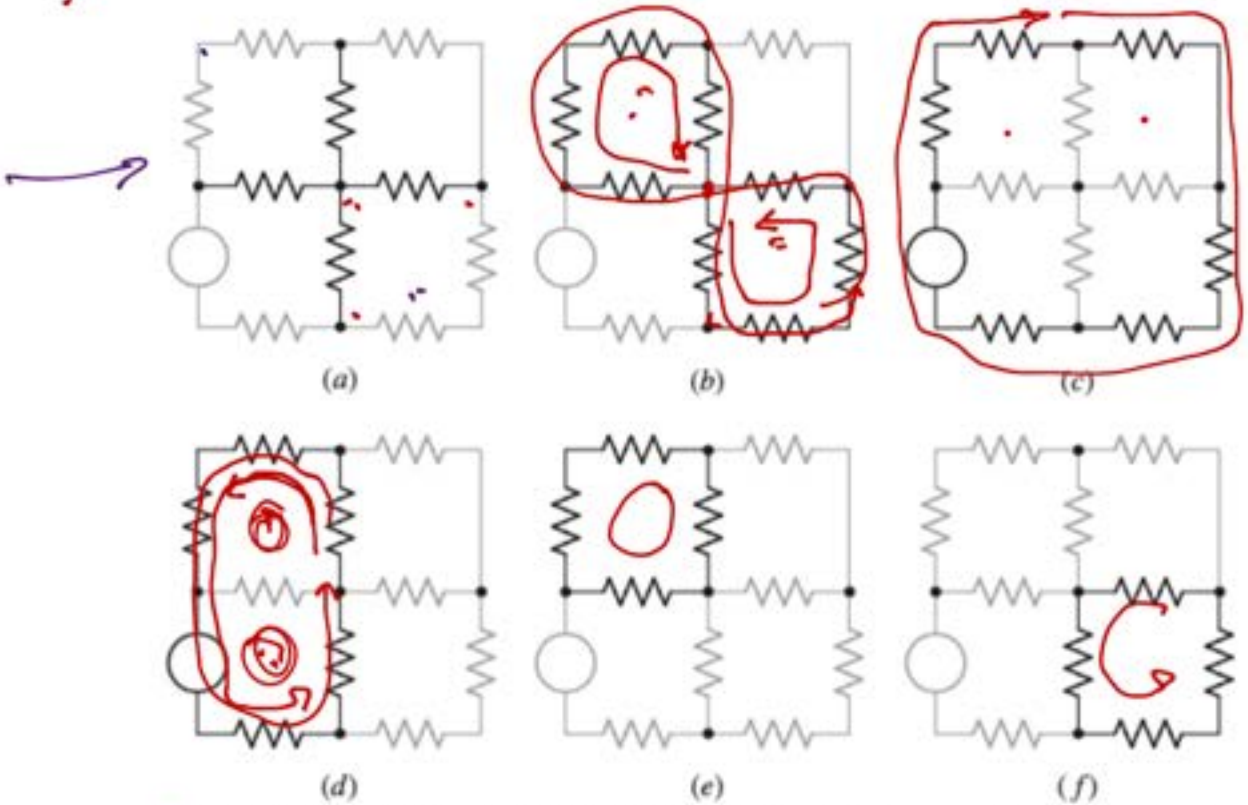


FIGURE 4.14 (a) The set of branches identified by the heavy lines is neither a path nor a loop. (b) The set of branches here is not a path, since it can be traversed only by passing through the central node twice. (c) This path is a loop but not a mesh, since it encloses other loops. (d) This path is also a loop but not a mesh. (e, f) Each of these paths is both a loop and a mesh.

PRACTICE

4.6 Determine i_1 and i_2 in the circuit in Fig. 4.18.

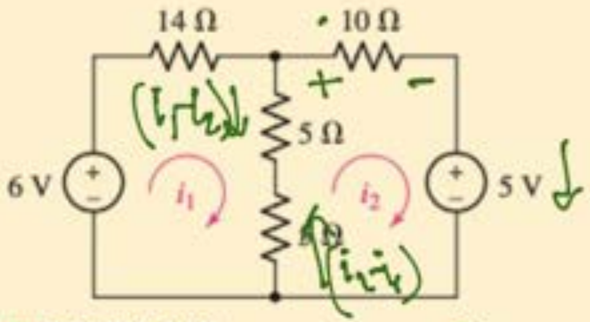
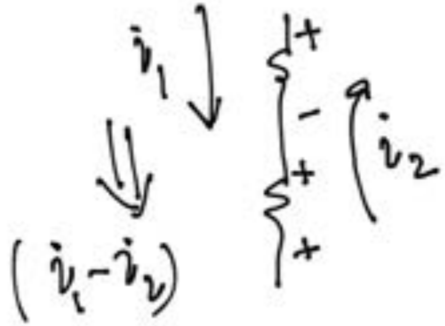


FIGURE 4.18



i_1 & i_2

KVL @ I $\quad +6V - 14\,i_1 - 10\,(i_1 - i_2) = 0$

@ II $\quad -10(i_2 - i_1) - 10\,i_2 - 5V = 0$

P 4.6)

(I) KVL : $6 - 14i_1 - 10(i_1 - i_2) = 0$

$\Rightarrow 6 - 24i_1 + 10i_2 = 0 = 3 - 12i_1 + 5i_2 = 0$ —(1)

(II) KVL $-10(i_2 - i_1) - 10i_2 - 5 = 0$

$\Rightarrow 10i_1 - 20i_2 - 5 = 2i_1 - 4i_2 - 1 = 0$ —(2)

(1) + 6×(2)

$$\left.\begin{aligned} 3 - 12i_1 + 5i_2 &= 0 \\ -6 + 12i_1 - 24i_2 &= 0 \end{aligned}\right\}$$

$19i_2 = -3$

$i_2 = -157.89\,mA$

$$i_1 = [4(\underset{\times 10^{-3}}{-157.89}) + 1]/2 = 184.2\,mA$$

(Solved)

PRACTICE

4.8 Determine i_1 in the circuit of Fig. 4.23 if the controlling quantity A is equal to (*a*) $2i_2$; (*b*) $2v_x$.

Ans: (*a*) 1.35 A; (*b*) 546 mA.

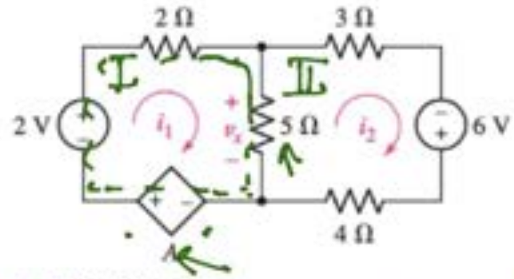


FIGURE 4.23

(a) $A = 2i_2$ (CCVS) (b) $A = 2v_x$ (VCVS)

Dependent Voltage Source

KVL @ I

$$A + 2 - 2(i_1) - 5(i_1 - i_2)$$

$$2i_2 + 2 - 2i_1 - 5i_1 + 5i_2 = 0 \quad \text{— (1)}$$

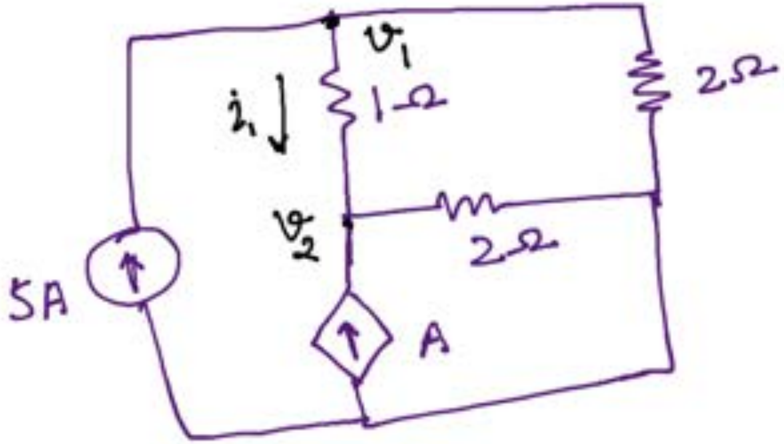
$$2v_x + 2 - 2i_1 - 5i_1 + 5i_2 = 0 \quad \text{— (3) (b)}$$

KVL @ II

$$\rightarrow -5(i_2 - i_1) - 3i_2 + 6 - 4i_2 = 0 \quad \text{— (2)}$$

$$v_x = 5(i_1 - i_2) \quad \text{(case b)}$$

Ex 4.8



$A = 2i_1$

$i_1 = \frac{v_1 - v_2}{1}$

KCL @ v_1 $\quad 5A - \frac{v_1 - v_2}{1} - \frac{v_1}{2} = 0 \Rightarrow -3v_1 + 2v_2 + 10 = 0$ — ①

KCL @ v_2 $\quad A - \frac{v_2}{2} + \frac{v_1 - v_2}{1} = 0 \Rightarrow 6v_1 - 7v_2 = 0$ — ②

$3v_2 = 20$

$v_1 = \frac{7}{6} \times \frac{20}{3} = \frac{70}{9}$ V

$A = 2v_1$ $\quad$ ② $\Rightarrow$ $2v_1 - v_2 + 2v_1 - 2v_2 = 0 \Rightarrow 4v_1 - 3v_2 = 0$ — ②

$-3v_1 + 2v_2 + 10 = 0$

P 4.8

Fig 4.23

$A = 2i_2$

KVL① $2 - 2i_1 - 5(i_1 - i_2) + 2i_2 = 0$

$2 - 7i_1 + 7i_2 = 0$ —— ①

KVL② $-5(i_2 - i_1) - 3i_2 + 6 - 4i_2 = 0$

$5i_1 - 12i_2 + 6 = 0$ —— ②

PRACTICE

4.8 Determine i_1 in the circuit of Fig. 4.23 if the controlling quantity A is equal to (*a*) $2i_2$; (*b*) $2v_x$.

Ans: (*a*) 1.35 A; (*b*) 546 mA.

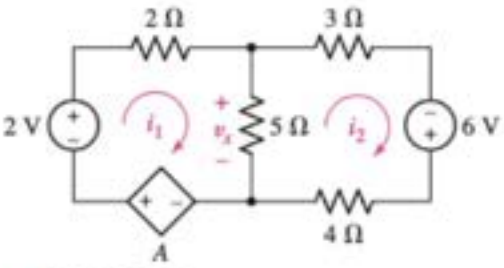


FIGURE 4.23

CHAPTER 5

Linear Elements :

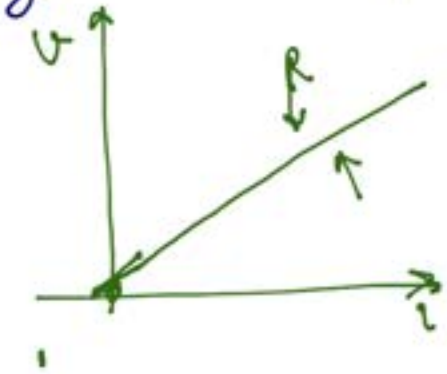
Linear current-voltage relationship

$v \propto i$

$v = \text{'}R\text{'}\, i$

$\downarrow$

constants



Linear dependent voltage/current sources

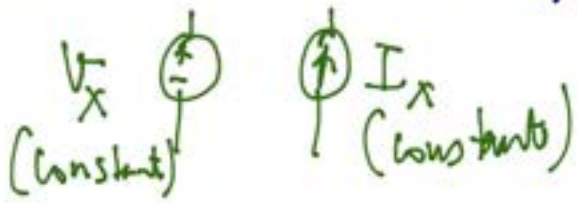
Outputs are dependent on 1^{st} power of the v_x or i_x.

$\cancel{Kx\,v_x^2}$

Linear Circuits

Containts only linear element, independent sources or linearly dependent sources.

⇒ Response (output) is proportional to the source (independent)



Superposition Principle

• Response of a linear circuit with more than one independent source can be obtained by adding the response from individual source.

V_s & I_s for Superposition

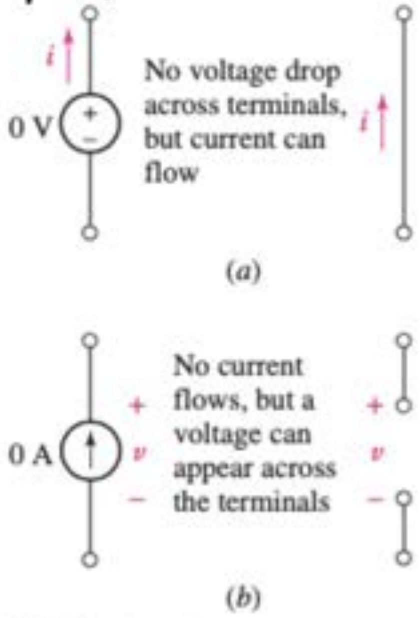


FIGURE 5.2 (*a*) A voltage source set to zero acts like a short circuit. (*b*) A current source set to zero acts like an open circuit.

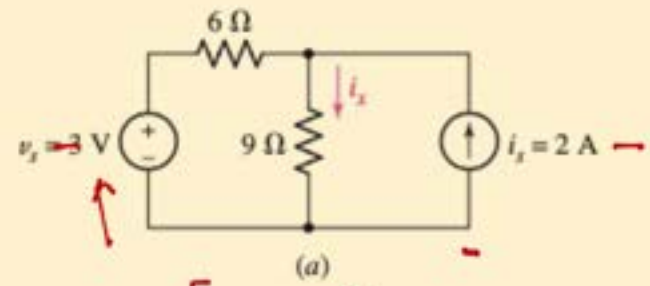
Applying Superposition

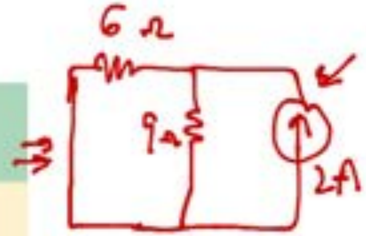
Voltages → Short

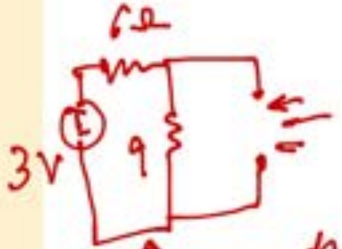
Current Sources → open

Example 5.1

For the circuit of Fig. 5.3*a*, use superposition to determine the unknown branch current i_x.

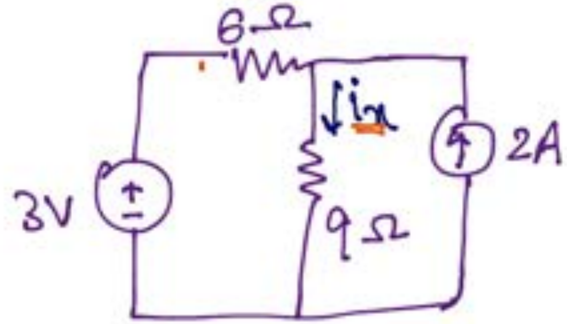




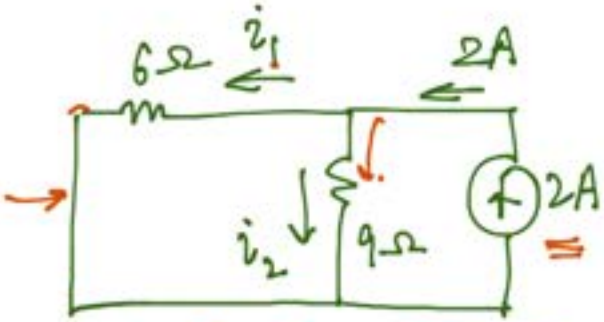


↑ Responds due to voltage

Ex 5.1



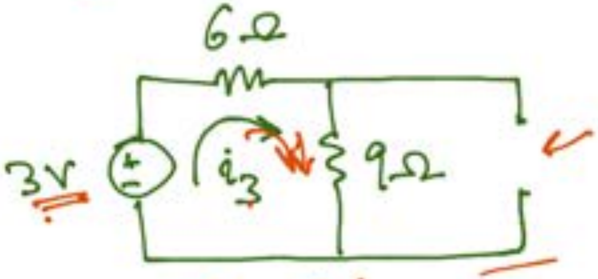
$$i_x = i_2 + i_3$$



$$i_1 = \frac{9}{15} * 2 = \frac{6}{5} = 1.2A$$

$$i_2 = \frac{6}{15} * 2 = \frac{4}{5} = \underline{0.8A}$$

Response from I source



$$i_3 = \frac{3}{15} = \frac{1}{5} = \underline{0.2A}$$

Response from V source

$$\underline{\underline{i_x}} = i_2 + i_3 = 0.8A + 0.2A$$

$$= 1A$$

Example 5.2

Referring to the circuit of Fig. 5.5*a*, determine the maximum *positive* current to which the source I_x can be set before any resistor exceeds its power rating and overheats.

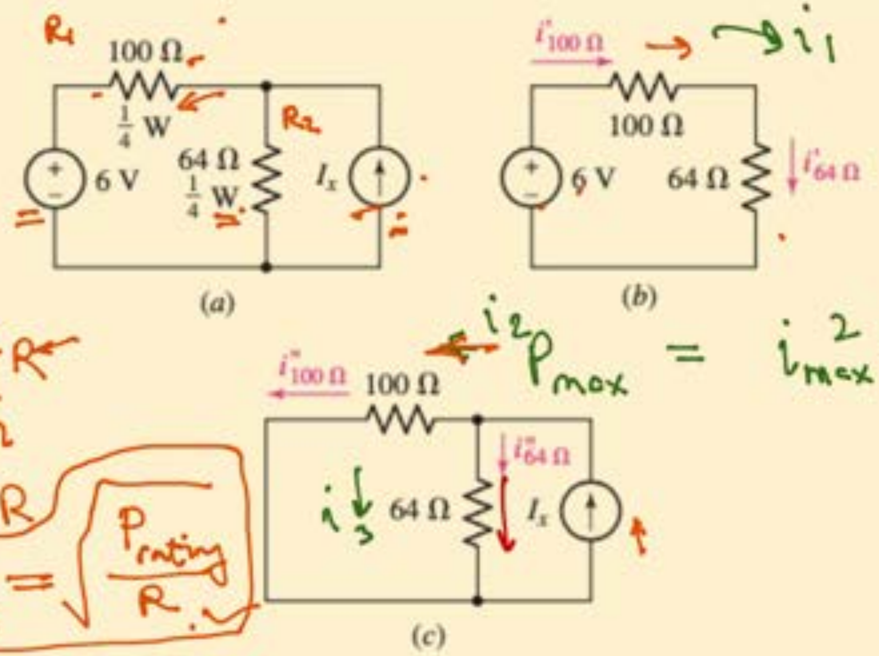


FIGURE 5.5 (*a*) A circuit with two resistors each rated at $\frac{1}{4}$ W. (*b*) Circuit with only the 6 V source active. (*c*) Circuit with the source I_x active.

$p = i^2 R$

$= V^2 / R$

$\boxed{i_{max} = \sqrt{\frac{P_{rating}}{R}}}$

$P_{max} = i_{max}^2 \cdot R$

$i_1 = \frac{6}{16.4}$ A $= 36.59$ mA

$i_2 = \frac{64}{164} I_x$

$i_3 = \frac{100}{164} I_x$

$i_{max}(100\,\Omega) = \pm\sqrt{\frac{P_{max}}{R}} = \sqrt{\frac{1/4}{100}}$

$= \frac{1}{20} = 0.05$ A

$i_{max}(64\,\Omega) = \sqrt{\frac{1/4}{64}} = \frac{1}{16} = 62.5$ mA

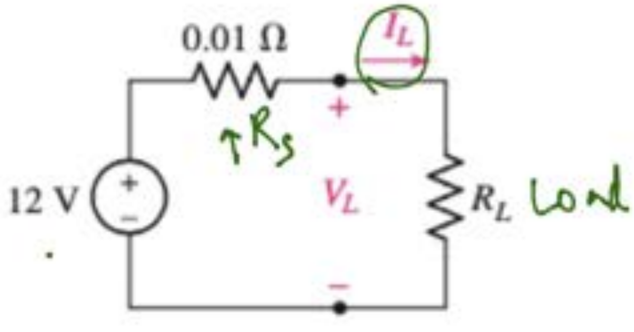
$i_{max} = \boxed{0.05 = i_1 - i_2 = 36.59\text{m} - \frac{64}{164} I_x} \rightarrow$

$62.5\text{ mA} = \frac{100}{164} I_x + 36.59\text{ mA} \rightarrow I_x -$

Summary of Basic Superposition Procedure

1. **Select one of the independent sources. Set all other independent sources to zero.** This means voltage sources are replaced with short circuits and current sources are replaced with open circuits. Leave dependent sources in the circuit.
2. **Relabel voltages and currents using suitable notation** (e.g., v', i_2''). Be sure to relabel controlling variables of dependent sources to avoid confusion.
3. **Analyze the simplified circuit to find the desired currents and/or voltages.**
4. **Repeat steps 1 through 3 until each independent source has been considered.**
5. **Add the partial currents and/or voltages obtained from the separate analyses.** Pay careful attention to voltage signs and current directions when summing.
6. **Do not add power quantities.** If power quantities are required, calculate only after partial voltages and/or currents have been summed.

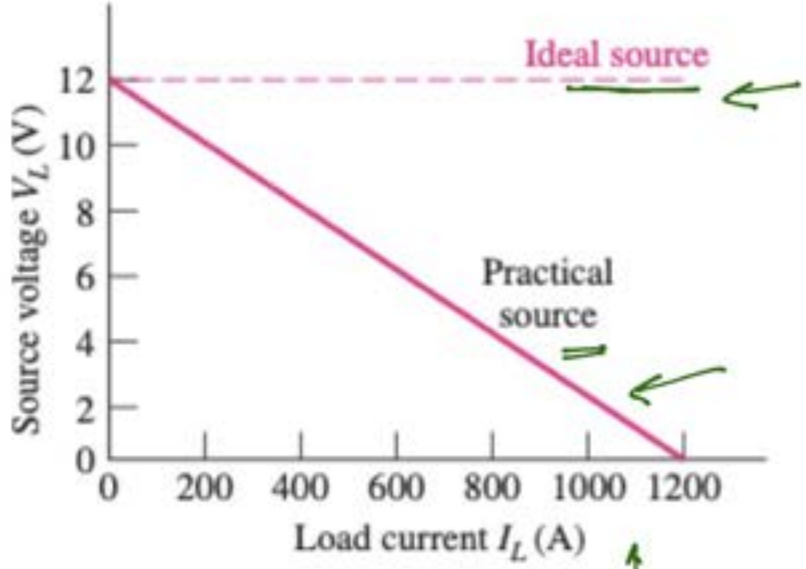
$\left.\begin{matrix} V_1 \\ V_2 \end{matrix}\right\}$ $\begin{matrix} P_1 \\ P_2 \end{matrix}$ $\cancel{P_1 + P_2}$ $i^2 R$ $i = i_1 + i_2$



(a)

Voltage Sources
(Non ideal)

R_s = Source Resistance
I_L = Current = Load Current



(b)

FIGURE 5.12 (a) A practical source, which approximates the behavior of a certain 12 V automobile battery, is shown connected to a load resistor R_L. (b) The relationship between I_L and V_L is linear.

$$V_s = I_L R_L + \underbrace{I_L R_s}_{\text{Drop across source Resistan}}$$

$$\text{'}I_L R_L\text{'} = V_s - I_L R_s$$

$I_L R_L$: Voltage across the Load

$I_L R_s$: Drop R_s

Voltage Source

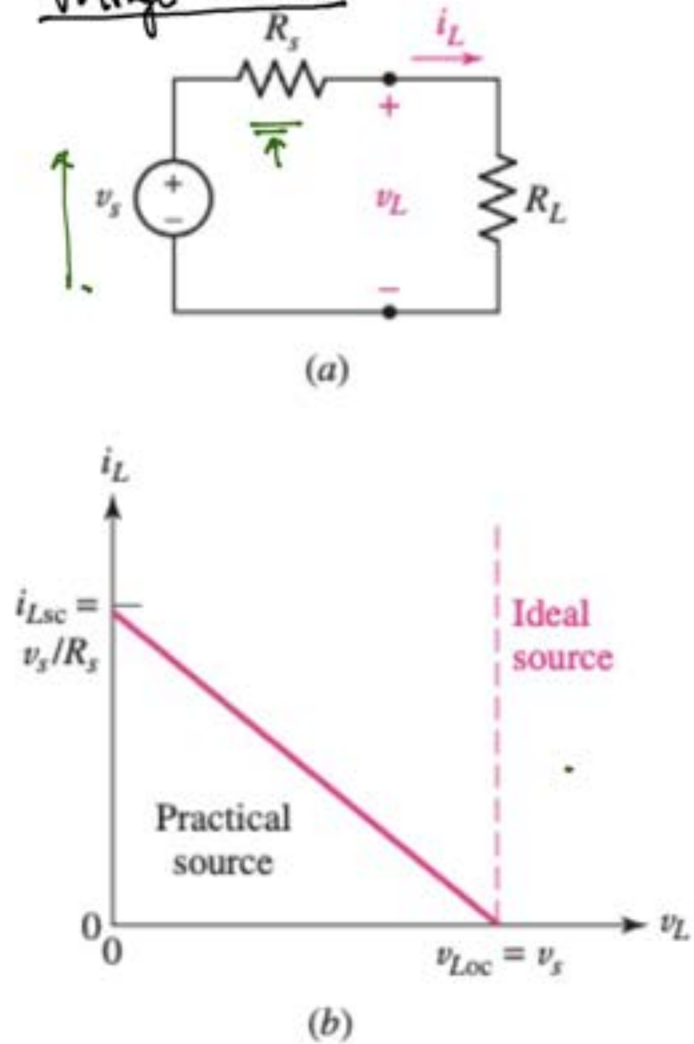
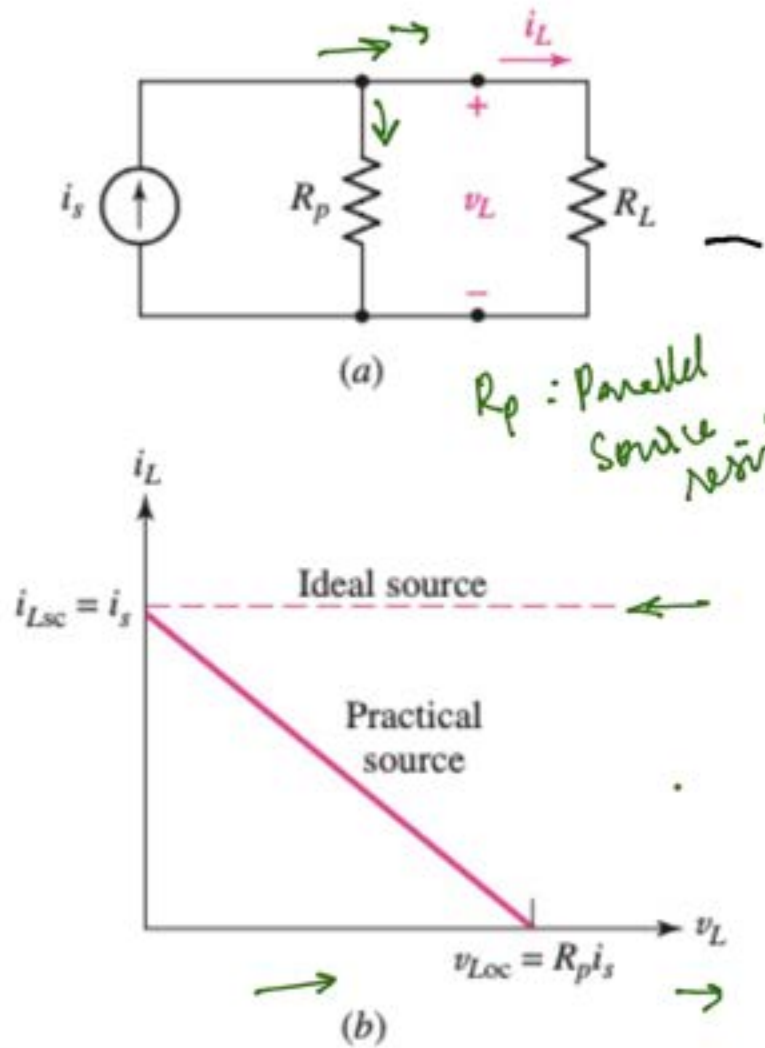


FIGURE 5.13 (*a*) A general practical voltage source connected to a load resistor R_L. (*b*) The terminal voltage of a practical voltage source decreases as i_L increases and $R_L = v_L/i_L$ decreases. The terminal voltage of an ideal voltage source (also plotted) remains the same for any current delivered to a load.

Current Source



R_p : Parallel source resistance

FIGURE 5.14 (*a*) A general practical current source connected to a load resistor R_L. (*b*) The load current provided by the practical current source is shown as a function of the load voltage.