Recap - Chapter 1

1

1. Introduction to concepts of basic variables in an electric circuit >> current, voltage & power.

2. Distinguished between power absorbed ($p=+Vi$) and power supplied ($p=-Vi$).

2

EEEB113 CIRCUIT ANALYSIS I

Chapter 2
Basic Laws

Materials from Fundamentals of Electric Circuits, Alexander & Sadiku 4e, The McGraw-Hill Companies, Inc.

Basic Laws - Chapter 2

3

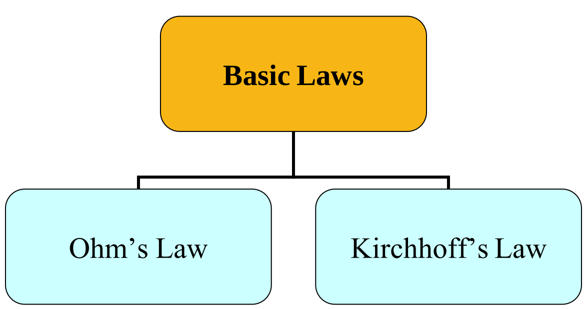
2.1 Introduction.
2.2 Ohm's Law.
2.3 Nodes, Branches & Loops.
2.4 Kirchhoff's Laws.
2.5 Series Resistors & Voltage Division.
2.6 Parallel Resistors & Current Division.
2.7 Wye-Delta Transformations.

2.1 Introduction

4

How to determine values of the basic variables in an electric circuit? What are the Basic Laws?

- Fundamental laws that govern the electric circuit.



2.2 Ohm's Law (1)

5

- **Ohm's Law**

The voltage across a resistor is directly proportional to the current, *i* flowing through the resistor.

$$\therefore v \propto i$$

- **Ohm further defined:** The constant of proportionality for a resistor to be the resistance, *R*.

$$\therefore \boxed{v = iR}$$

2.2 Ohm's Law (2)

6

- Thus, the resistance, *R* is the ability of an element to resist the flow of electric current; measured in ohms (Ω).

$$\therefore \boxed{R = \frac{v}{i}}$$

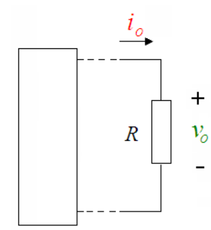
$$\Rightarrow 1\Omega = \frac{1\text{V}}{1\text{A}}$$

2.2 Ohm's Law (3)

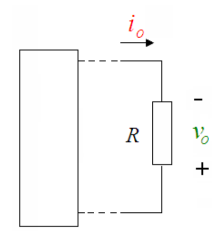
7

- **Passive sign convention**;

a) $v = iR$ >> current from hi pot. to lo pot.



b) $v = -iR$ >> current from lo pot. to hi pot.

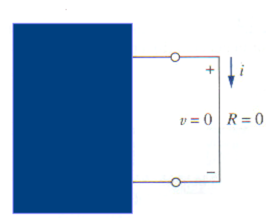


2.2 Ohm's Law (4)

8

- **Extreme cases:** As R can vary from 0 to ∞, it is important that we consider these two extreme possible values of R.

$R=0$ >> short circuit *(ideal circuit)*



(a) Short circuit ($R = 0$).

However, in practice, a short circuit is usually a connecting wire, assumed to be a perfect conductor.

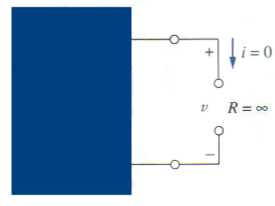
$\therefore$ A **short circuit** is a circuit that has circuit element with resistance approaching 0.

$$v = iR = 0 \qquad \therefore R \to 0 \quad ; \quad v = 0; \quad i = x$$

2.2 Ohm's Law (5)

9

$R = \infty$ >> open circuit



(b) Open circuit ($R = \infty$).

$\therefore$ A **open circuit** is a circuit that has circuit element with resistance approaching ∞.

$$i = \lim_{R \to \infty} \frac{v}{R} = 0 \qquad \therefore R \to \infty \quad ; \quad i = 0; \quad v = x$$

2.2 Ohm's Law (6)

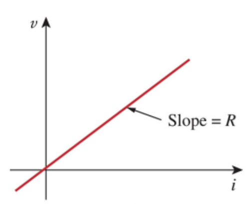
10

- **Resistors**

  Two types
  - **Fixed** : resistance remains constant.
  - **Variable** : have adjustable resistance.

- Not all resistors obey Ohm's Law.

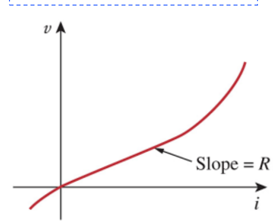
  a) Linear resistors obey *(e.g. normal resistors)*



(a)

However, throughout the course, ALL resistors are assumed LINEAR.

  b) Non-linear resistors do not obey. *(e.g. diode)*



(b)

2.2 Ohm's Law (7)

11

- **Conductance**

if $R = \frac{v}{i}$ → resist current,

then $\frac{1}{R} = \frac{i}{v}$ → conduct current.

This special quantity, $\frac{1}{R}$ is known as conductance of an element, G.

2.2 Ohm's Law (8)

12

- **Conductance** is a measurement of how well an element will <u>conduct</u> electric current.
- It is measured in mhos (℧) or siemens (S).

$$1S = 1℧ = 1\frac{\text{A}}{\text{V}}$$

- In this course, we will use the SI unit of siemens (S).

2.2 Ohm's Law (9)

13

- **Power in Resistor & Conductor**

Resistor : $p = vi = (iR)i = i^2 R = v\left(\frac{v}{R}\right) = \frac{v^2}{R}$

Conductor : $p = vi = v(vG) = v^2 G = \left(\frac{i}{G}\right)i = \frac{i^2}{G}$

Note that R and G are always positive. As is i^2 and v^2.

$\therefore$ Power dissipated in or absorbed by the resistor is always positive. Confirms theory - resistor is a passive element, cannot generate energy.

2.2 Ohm's Law (10)

14

- **Practice Problem 2.1**

  The essential component of a toaster is an electrical element (a resistor) that converts electrical energy to heat energy. How much current is drawn by a toaster with resistance 10Ω at 110V?

Solution

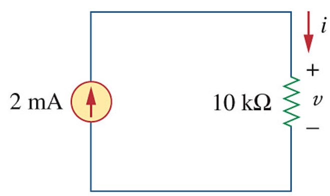
$i = V/R = 110/10 = \mathbf{11\ A}$

2.2 Ohm's Law (11)

15

- **Practice Problem 2.2**

  For the circuit shown below, calculate the voltage *v*, the conductance *G*, and the power *p*.



Solution

(a) $v = iR = 2\text{ mA} \times 10\text{ k}\Omega =$ **20 V**

(b) $G = 1/R = 1/10\text{ k}\Omega =$ **100 µS**

(c) $p = vi = 20\text{ volts} \times 2\text{ mA} =$ **40 mW**

2.2 Ohm's Law (12)

16

- **Practice Problem 2.3**

  A resistor absorbs an instantaneous power of $20\cos^2(t)$ mW when connected to a voltage source $v = 10\cos(t)$ V. Find *i* and *R*.

Solution

$p = vi$ thus, $i = p/v = [20\cos^2(t)\text{ mW}]/[10\cos(t)\text{ V}]$
$= \mathbf{2\cos(t)\text{ mA}}$

$R = v/i = [10\cos(t)\text{ V}]/[2\cos(t)\text{ mA}]$
$= \mathbf{5\text{ k}\Omega}$

2.3 Nodes, Branches & Loops (1)

17

- A **branch** represents a single element (voltage source, current source or resistor).
- A **node** is the point of connection between 2 or more branches.
- A **loop** is any closed path in a circuit.

2.3 Nodes, Branches & Loops (2)

18

- A network with 'b' branches, 'n' nodes, and 'l' independent loops will satisfy the **fundamental theorem of network topology**:

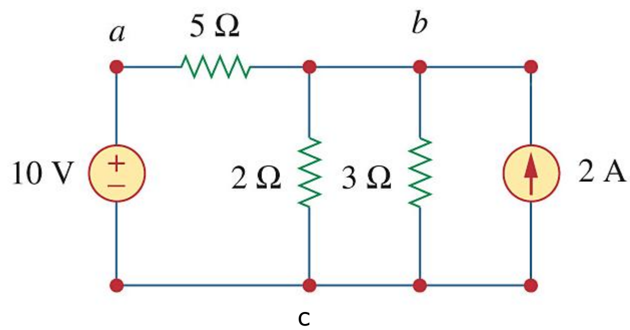
$$b = l + n - 1$$

- ≥ 2 elements are in **series** if they exclusively share a single node.
- ≥ 2 elements are in **parallel** if they are connected to the same 2 nodes.

2.4 Nodes, Branches & Loops (3)

19

Example 1

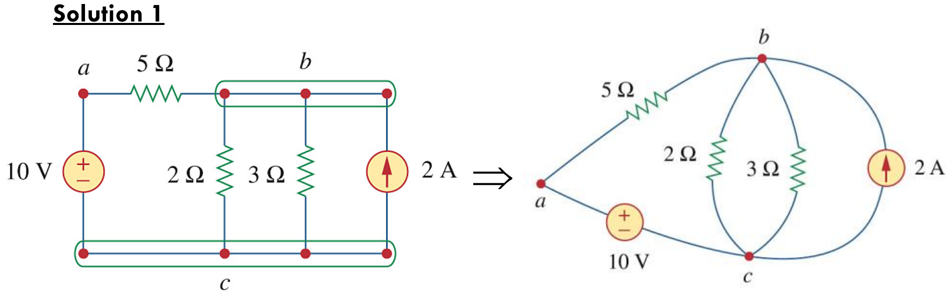


How many branches, nodes and loops are there?

2.4 Nodes, Branches & Loops (4)

20

Solution 1



Original circuit

Equivalent circuit

5 branches, 3 nodes and 3 loops

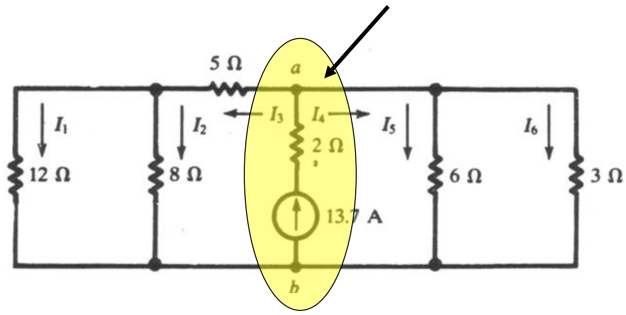
$$\boxed{b = l + n - 1} \qquad \therefore 5 = 3 + 3 - 1$$

2.3 Nodes, Branches & Loops (5)

21

Example 2

Should we consider it as one branch or two branches?



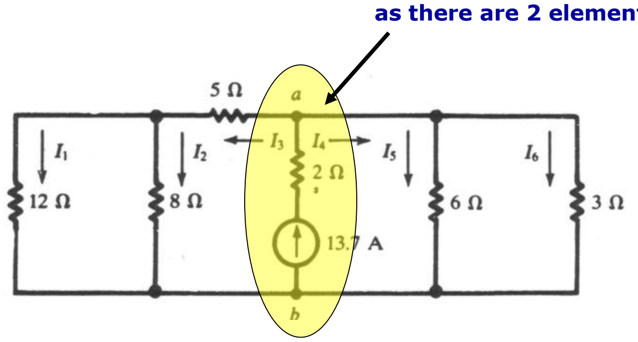
How many branches, nodes and loops are there?

2.3 Nodes, Branches & Loops (6)

22

Solution 2

Consider as two branches, as there are 2 elements.



7 branches, 4 nodes and 4 loops

$$\boxed{b = l + n - 1} \qquad \therefore 7 = 4 + 4 - 1$$

2.4 Kirchhoff's Laws (1)

23

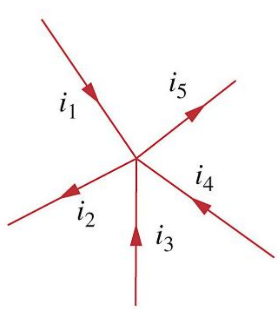
Kirchhoff's Laws

- **Kirchhoff's Current Law (KCL)**
- **Kirchhoff's Voltage Law (KVL)**

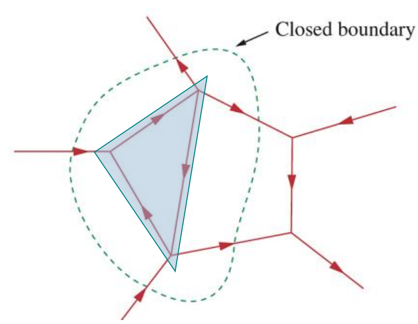
2.4 Kirchhoff's Laws (2)

24

- **KCL** : the algebraic **sum of currents** entering a node (or a closed boundary) is **zero**.



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



N = no. of branches connected to the node;

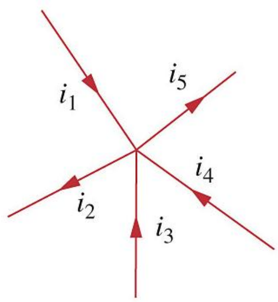
i_n = nth current entering the node.

2.4 Kirchhoff's Laws (3)

25

- **Alternatively**, the **sum of currents entering** a node **equals** the **sum of currents leaving** a node.

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



Example:

$$i_1 - i_2 + i_3 + i_4 - i_5 = 0$$

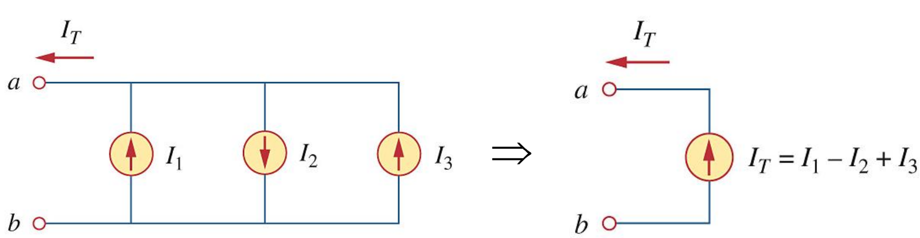
or

$$i_1 + i_3 + i_4 = i_2 + i_5$$

2.4 Kirchhoff's Laws (4)

26

- **KCL** can be applied to obtain the combined current, when **current sources are connected in parallel**.



Original circuit

Equivalent circuit

2.4 Kirchhoff's Laws (5)

27

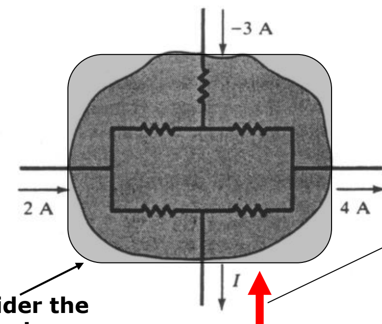
Example 3

- Determine the current I for the circuit shown in the figure below.

-I − 4 + (-3) +2 = 0

I + 4-(-3)-2 = 0

⇒I = -5A



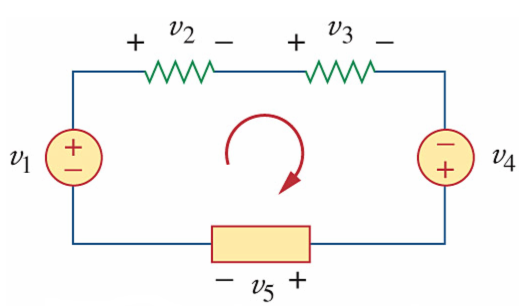
We can consider the whole enclosed area as one "node".

This indicates that the actual current for I is flowing in the opposite direction.

2.4 Kirchhoff's Laws (6)

28

- **KVL** : the algebraic **sum of all voltages** around a closed path (or loop) is **zero**.



$$\sum_{m=1}^{M} v_m = 0$$

M = no. of voltages (or no. of branches) in a loop;

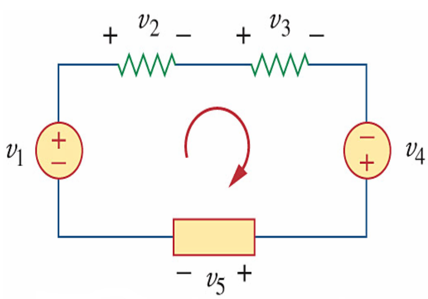
v_m = mth voltage.

2.4 Kirchhoff's Laws (7)

29

- **Alternatively,** the sum of voltage drops equals the sum of voltage rise.

$$\sum v_{drop} = \sum v_{rise}$$



Example:

$$-v_1 + v_2 + v_3 - v_4 + v_5 = 0$$

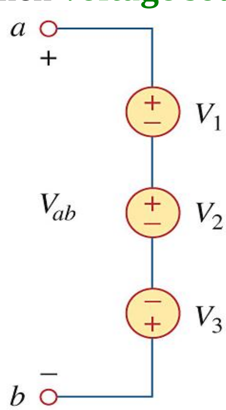
or

$$v_2 + v_3 + v_5 = v_1 + v_4$$

2.4 Kirchhoff's Laws (8)

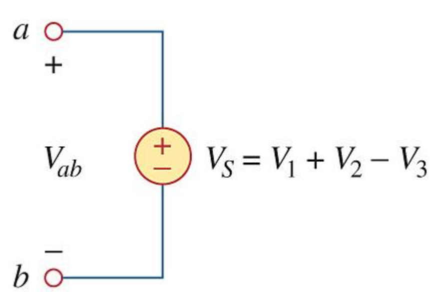
30

- **KVL** can be applied to obtain the combined voltage, when **voltage sources are connected in series**.



Original circuit

$\Rightarrow$



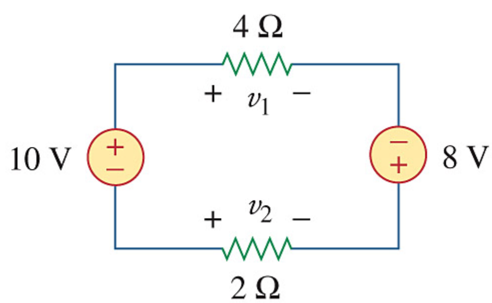
Equivalent circuit

2.4 Kirchhoff's Laws (9)

31

Practice Problem 2.5

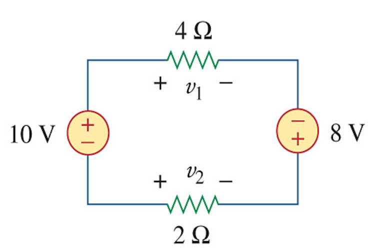
Find v_1 and v_2 in the circuit given below.



2.4 Kirchhoff's Laws (10)

32

Solution to Practice Prob. 2.5



Applying KVL to the loop we get:

$-10 + 4i - 8 + 2i = 0$ which leads to $i = 3A$

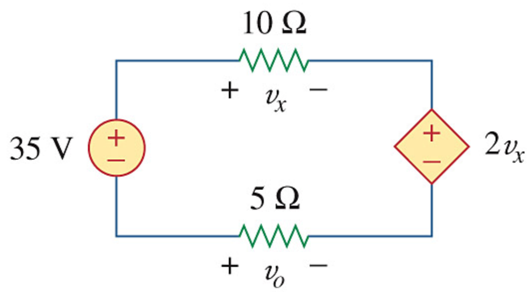
$v_1 = 4i = \underline{\mathbf{12V}}$ and $v_2 = -2i = \underline{\mathbf{-6V}}$

2.4 Kirchhoff's Laws (11)

33

Practice Problem 2.6

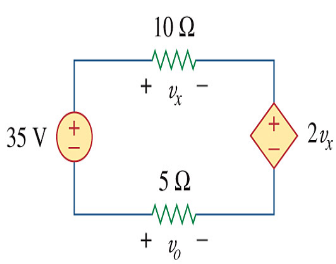
Find v_x and v_o in the circuit given below.



2.4 Kirchhoff's Laws (12)

34

Solution to Practice Prob. 2.6



Applying KVL to the loop we get:

$-35 + 10i + 2v_x + 5i = 0$

But, $v_x = 10i$ and $v_0 = -5i$. Hence,

$-35 + 10i + 20i + 5i = 0$ which leads to $i = 1A$.

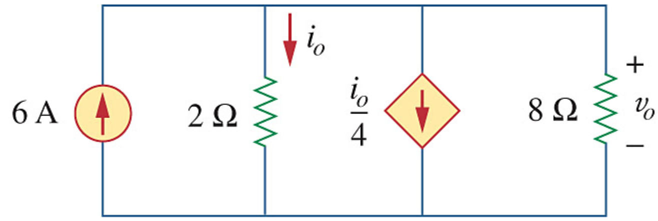
Thus, v_x = **10V** and v_0 = **–5V**

2.4 Kirchhoff's Laws (13)

35

Practice Problem 2.7

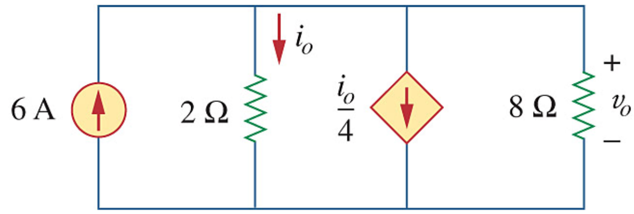
Find v_o and i_o in the circuit given below.



2.4 Kirchhoff's Laws (14)

36

Solution to Practice Prob. 2.7



Applying KCL, $6 = i_0 + [i_0 /4] + [v_0 /8]$, but $i_0 = v_0/2$

Which leads to: $6 = (v_0/2) + (v_0/8) + (v_0/8)$

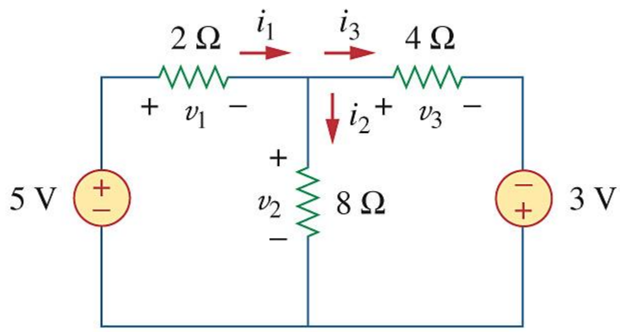
thus, $v_0 =$ **8V** and $i_0 =$ **4A**

2.4 Kirchhoff's Laws (15)

37

Practice Problem 2.8

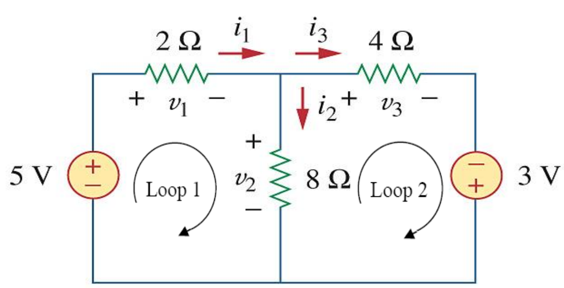
Find the currents and voltages in the circuit shown in the circuit given below.



2.4 Kirchhoff's Laws (16)

Solution to Practice Prob. 2.8

38



KCL	At the top node,	$i_1 = i_2 + i_3$	(1)
KVL	For loop 1 or	$-5 + V_1 + V_2 = 0$ $V_1 = 5 - V_2$	(2)
KVL	For loop 2 or	$-V_2 + V_3 - 3 = 0$ $V_3 = V_2 + 3$	(3)

2.4 Kirchhoff's Laws (17)

cont. Solution to Practice Prob. 2.8

39

Using (1) and Ohm's law, we get

$$(V_1/2) = (V_2/8) + (V_3/4)$$

and now using (2) and (3) in the above yields

$$[(5- V_2)/2] = (V_2/8) + (V_2+3)/4$$

or $V_2 = \underline{\mathbf{2\ V}}$

$V_1 = 5- V_2 = \underline{\mathbf{3V}}$, $V_3 = 2+3 = \underline{\mathbf{5V}}$, $i_1 = (5-2)/2 = \underline{\mathbf{1.5A}}$,
$i_2 = \underline{\mathbf{250\ mA}}$, $i_3 = \underline{\mathbf{1.25A}}$

2.5 Series Resistors & Voltage Division (1)

40

- **What is Series?**

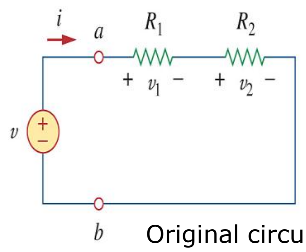
  Two or more elements are in series if they exclusively share a single node and consequently carry the same current.

- The equivalent resistance of any number of resistors connected in a series is the sum of the individual resistances.

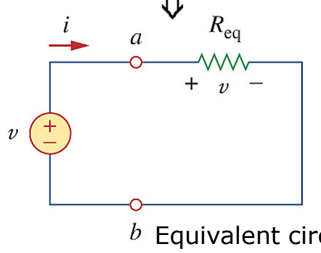
$$R_{eq} = R_1 + R_2 + \cdots + R_N = \sum_{n=1}^{N} R_n$$

2.5 Series Resistors & Voltage Division (2)

41



Original circuit



Equivalent circuit

Apply **KVL** (clockwise dir.)

$$-v + v_1 + v_2 = 0$$

Apply **Ohm's Law**

$$-v + iR_1 + iR_2 = 0$$

$$i(R_1 + R_2) = v$$

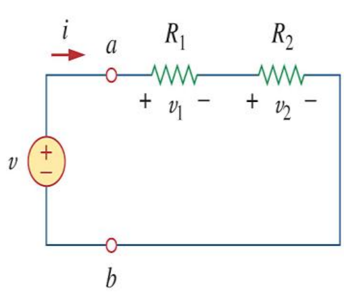
$$i = \frac{v}{R_1 + R_2} = \frac{v}{R_{eq}}$$

$$\therefore R_{eq} = R_1 + R_2$$

2.5 Series Resistors & Voltage Division (3)

42

- To determine the voltage across each resistor;



Ohm's Law

$$v_1 = iR_1, \quad v_2 = iR_2$$

Substitute: $i = \dfrac{v}{R_{eq}} = \dfrac{v}{R_1 + R_2}$

$$v_1 = \frac{R_1}{R_1 + R_2} v, \quad v_2 = \frac{R_2}{R_1 + R_2} v$$

2.5 Series Resistors & Voltage Division (4)

43

- Note that source voltage v is divided among the resistors in direct proportion to their resistances.

  $\Rightarrow$ ***principle of voltage division***

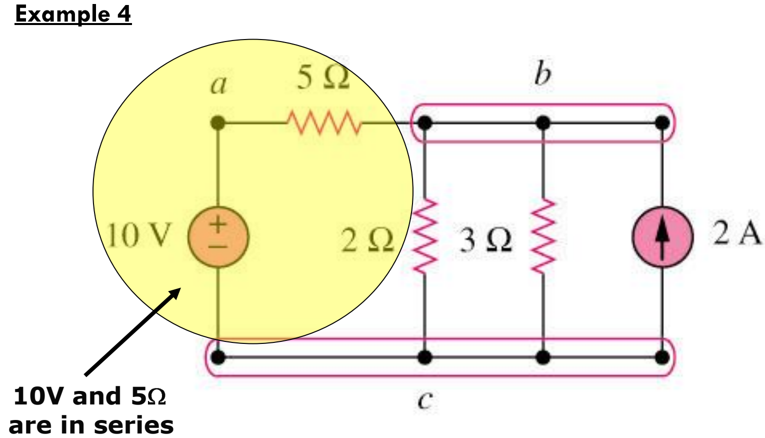
- In general, if a voltage supply has N resistors in series with the source voltage v, the nth resistor (R_n) can be expressed as:

$$v_n = \frac{R_n}{R_1 + R_2 + \cdots + R_N} v$$

2.5 Series Resistors & Voltage Division (5)

44

Example 4



2.6 Parallel Resistors & Current Division (1)

45

- **What is Parallel?**

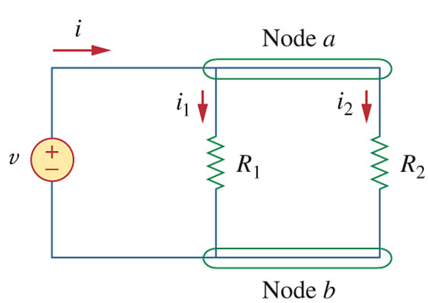
  Two or more elements are in parallel if they are connected to the same two nodes and consequently have the same voltage across them.

- The equivalent resistance of 2 parallel resistors is equal to the product of their resistances divided by their sum.

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

2.6 Parallel Resistors & Current Division (2)

46



Apply **KCL** at node a

$$i = i_1 + i_2$$

Apply **Ohm's Law**

$$i = \frac{v}{R_1} + \frac{v}{R_2} = v\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{v}{R_{eq}}$$

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

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

2.6 Parallel Resistors & Current Division (3)

47

- The equivalent resistance of a circuit with N resistors in parallel is:

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

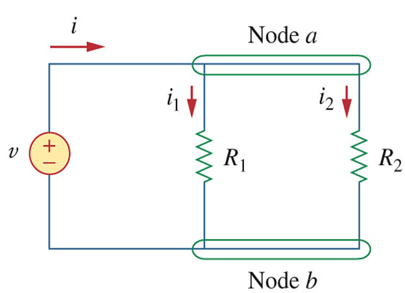
- The equivalent conductance of a circuit with N resistors in parallel is the sum of their individual conductance:

$$G_{eq} = G_1 + G_2 + \cdots + G_N$$

2.6 Parallel Resistors & Current Division (4)

48

- To determine the current through each resistor;



Ohm's Law

$$i_1 = \frac{v}{R_1}, \quad i_2 = \frac{v}{R_2}$$

Substitute: $v = iR_{eq} = \dfrac{iR_1R_2}{R_1 + R_2}$

$$i_1 = \frac{iR_2}{R_1 + R_2}, \quad i_2 = \frac{iR_1}{R_1 + R_2}$$

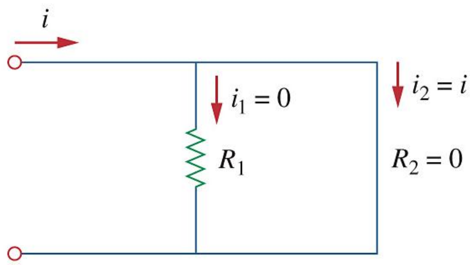
2.6 Parallel Resistors & Current Division (5)

49

- Note that the total current i is shared by the resistors in inverse proportion to their resistances.

  $\Rightarrow$ ***principle of current division***

- **Extreme cases:**



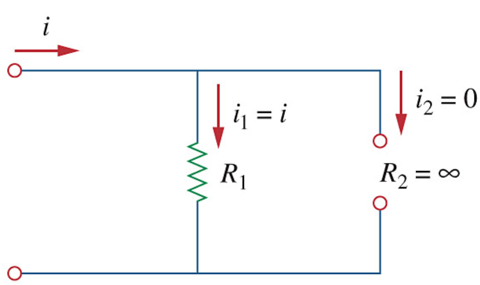
shorted circuit

When $R_2=0$, the entire current i bypasses R_1 and flows through the short circuit $R_2=0$, the path of least resistance.

2.6 Parallel Resistors & Current Division (6)

50

- **cont. Extreme cases:**



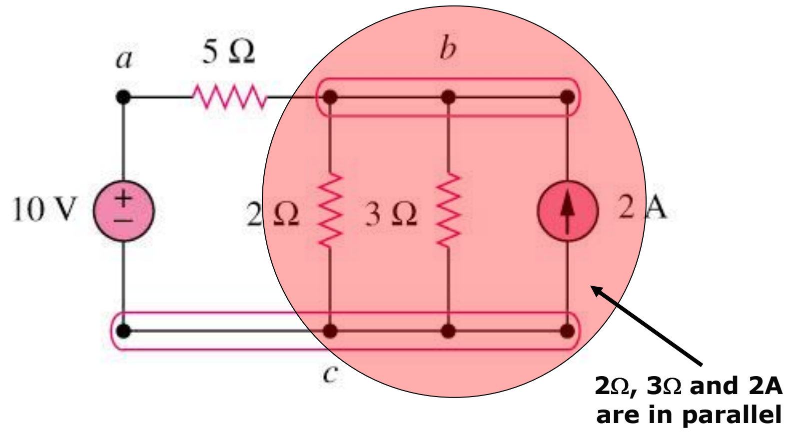
open circuit

When $R_2=\infty$, the entire current i bypasses open circuited R_2 and flows through R_1, the path of least resistance.

2.6 Parallel Resistors & Current Division (7)

51

Example 5

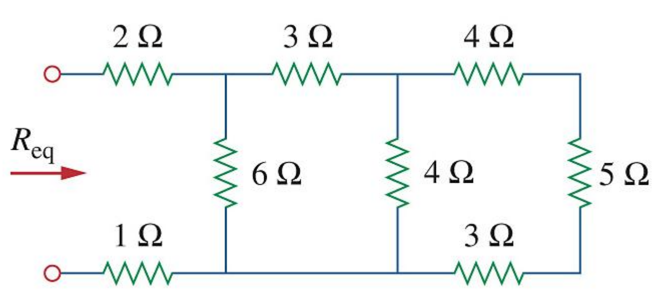


2.6 Parallel Resistors & Current Division (8)

52

Practice Problem 2.9

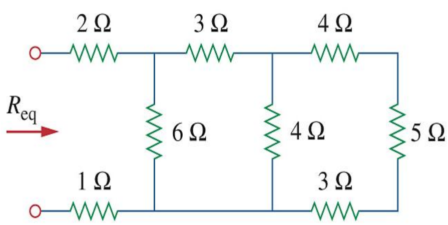
By combining the resistors in the circuit below, find R_{eq}



2.6 Parallel Resistors & Current Division (9)

Soln to Practice Prob 2.9

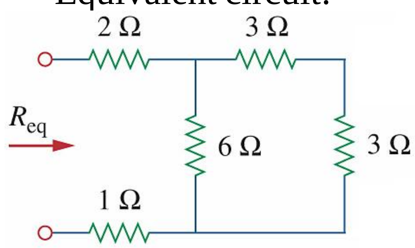
53



Combining the 4Ω, 5Ω and 3Ω resistors in series gives 4+5+3 = 12 Ω

Then, 4Ω //12Ω gives [4x12]/[4+12] = 3Ω

∴ Equivalent circuit:



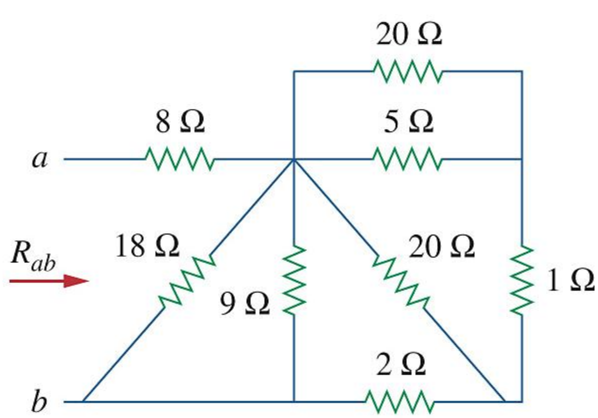
Thus, R_{eq} = 1 + 2 + 6//6 = 6Ω

2.6 Parallel Resistors & Current Division (10)

54

Practice Problem 2.10

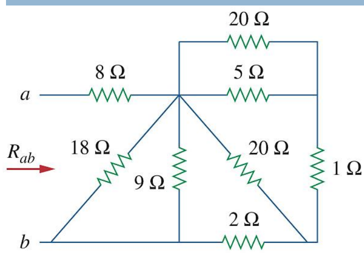
Find R_{ab} for the circuit shown below.



2.6 Parallel Resistors & Current Division (11)

Soln to Practice Prob 2.10

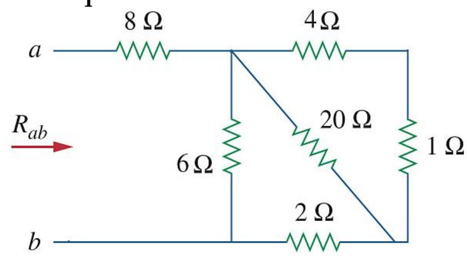
55



Combining 18Ω // 9Ω gives [9x18]/[9+18] = 6Ω

Then, 5Ω //20Ω gives [5x20]/[5+20] = 4Ω

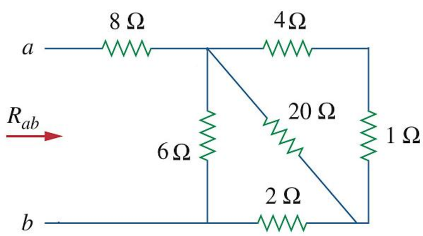
∴ Equivalent circuit:



2.6 Parallel Resistors & Current Division (12)

cont. Soln to Practice Prob 2.10

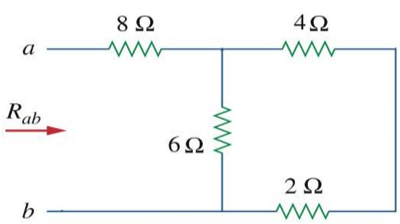
56



Combine 4Ω and 1Ω, get 5Ω.

Then 5//20 gives 4Ω.

∴ Equivalent circuit:



Combine 4Ω and 2Ω, get 6Ω.

Then 6//6 gives 3Ω.

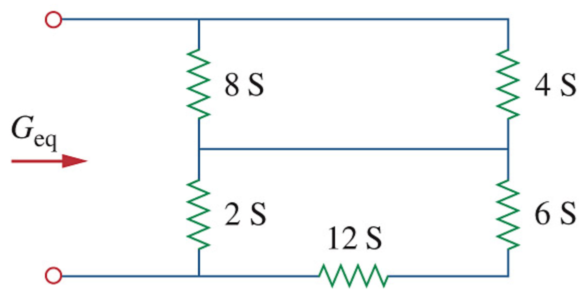
Thus, *R*eq = 8 + 3
= 11Ω

2.6 Parallel Resistors & Current Division (13)

57

Practice Problem 2.11

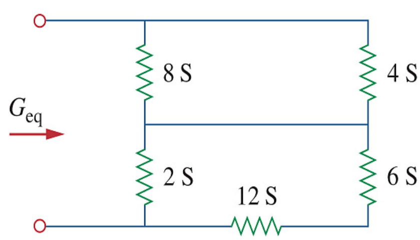
Calculate G_{eq} for the circuit shown below.



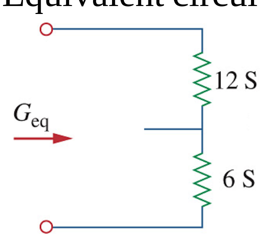
2.6 Parallel Resistors & Current Division (14)

Soln to Practice Prob 2.11

58



∴ Equivalent circuit:



8//4 = 8+4 = 12 S

6 in series with 12 =
[6x12][6+12] = 4 S

4//2 = 4+2 = 6 S

12 in series with 6 =
[12x6][12+6] = 4 S

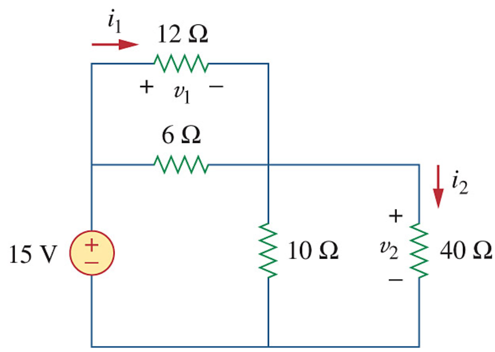
Thus, G_{eq} = 4 S

2.6 Parallel Resistors & Current Division (15)

59

Practice Problem 2.12

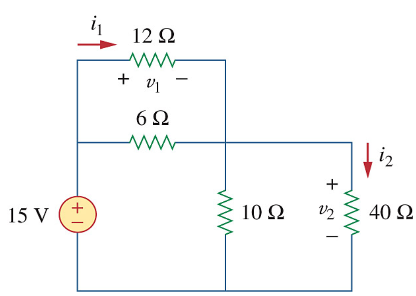
Find v_1 and v_2 for the circuit shown below. Also calculate i_1 and i_2 and the power dissipated in the 12Ω and 40Ω resistors.



2.6 Parallel Resistors & Current Division (16)

Soln to Practice Prob 2.12

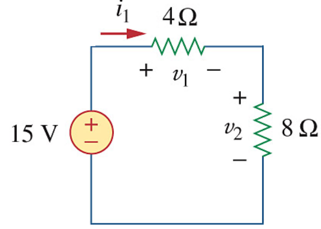
60



12//6 = [6x12][6+12] = 4

10//40 = [10x40][10+40] = 8

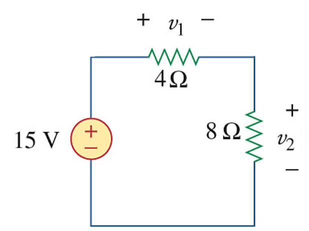
∴ Equivalent circuit:



2.6 Parallel Resistors & Current Division (17)

cont. Soln to Practice Prob 2.12

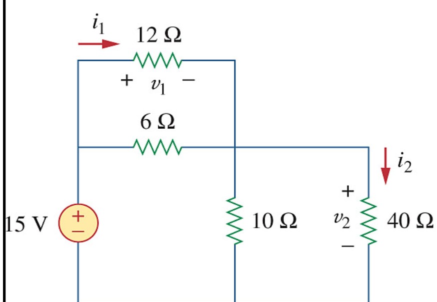
61



Use **voltage division**,

v_1 = [4/(4+8)](15) = 5V

v_2 = [8/(4+8)](15) = 10V



$i_1 = v_1/12$ = 5/12 = 416.7mA

$i_2 = v_2/40$ = 10/40 = 250mA

$p_1 = v_1 i_1$ = 5x(5/12) = 2.083W

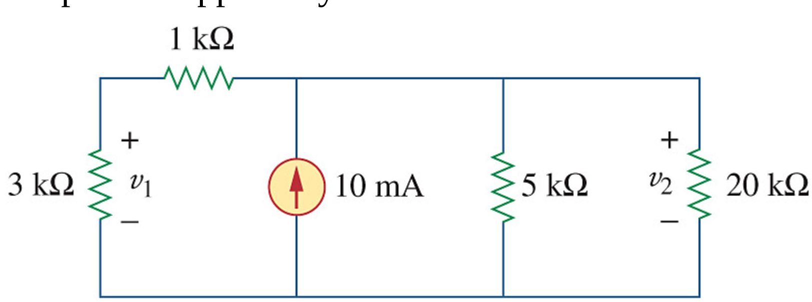
$p_2 = v_2 i_2$ = 10x(0.25) = 2.5W

2.6 Parallel Resistors & Current Division (18)

62

Practice Problem 2.12

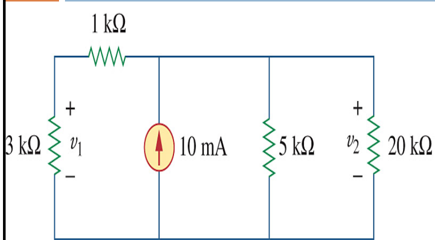
For the circuit given below, find: (a) v_1 and v_2 , (b) the power dissipated in the 3kΩand 20kΩ resistors, and (c) the power supplied by the current source.



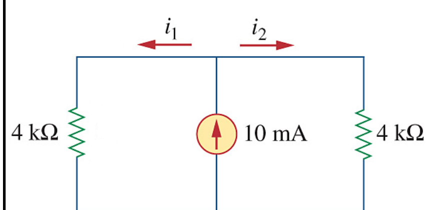
2.6 Parallel Resistors & Current Division (19)

Soln to Practice Prob 2.13

63



Simplify circuit, to get:



Use current division,

$i_1 = i_2 = 10mA[4/(4+4)] = 5mA$

Ohms' Law

$v_1 = 5mA \times 3k = 15V$

$v_2 = 5mA \times 4k = 20V$

$p_{3k} = v_1 i_1 = 15 \times 5mA = 75mW$

$p_{20k} = v_2^2/20k = 400/20k = 20mW$

Power supplied, $p_o = v_o i_o$

$v_o = 4k \times i_1 = 4k \times i_2 = 20V$

$p_o = 20V \times 10mA = 200mW$

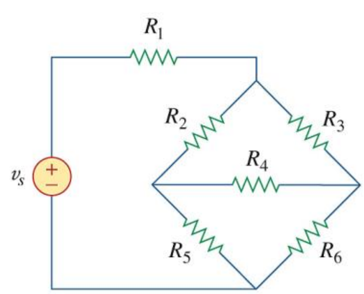
2.7 Wye-Delta Transformations (1)

64

- **Why Transform?**

  Often, in circuit analysis, the resistors are NOT in parallel nor series.

Example:



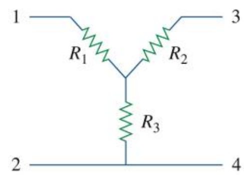
- The equivalent resistance is found by simplifying circuits using three-terminal equivalent networks.

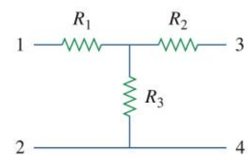
2.7 Wye-Delta Transformations (2)

65

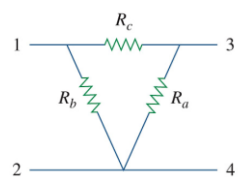
- **Three-terminal network equivalents**

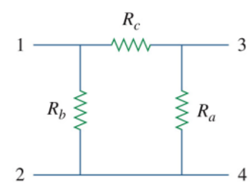
(i) wye (Y) or tee (T)





(ii) delta (Δ) or pi (∏)

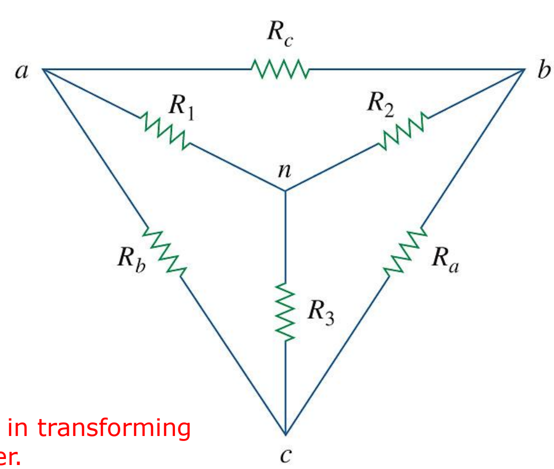




2.7 Wye-Delta Transformations (3)

66

- **Superposition of Y and Δ networks**



Used as an aid in transforming one to the other.

2.7 Wye-Delta Transformations (4)

67

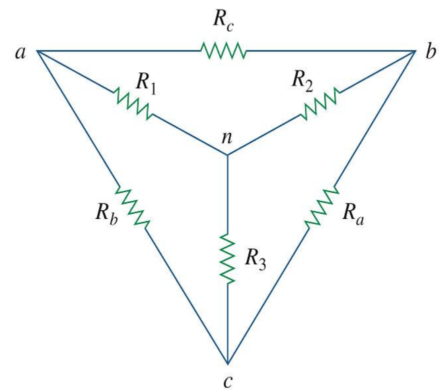
- **Delta to Wye Conversion**

Each resistor in the Y network is a product of the resistors in adjacent Δ branches, divided by the sum of the three Δ resistors.

$$R_1 = \frac{R_b R_c}{(R_a + R_b + R_c)}$$

$$R_2 = \frac{R_c R_a}{(R_a + R_b + R_c)}$$

$$R_3 = \frac{R_a R_b}{(R_a + R_b + R_c)}$$



2.7 Wye-Delta Transformations (5)

68

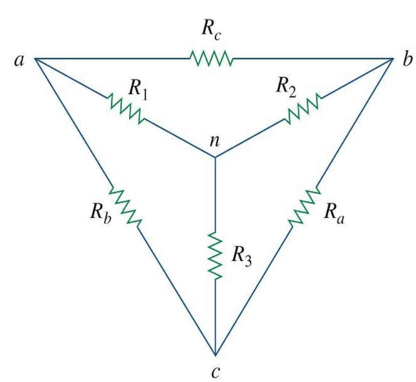
- **Wye to Delta Conversion**

Each resistor in the Δ network is the sum of all possible products of Y resistors taken two at a time, divided by the opposite Y resistor.

$$R_a = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_1}$$

$$R_b = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_2}$$

$$R_c = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_3}$$

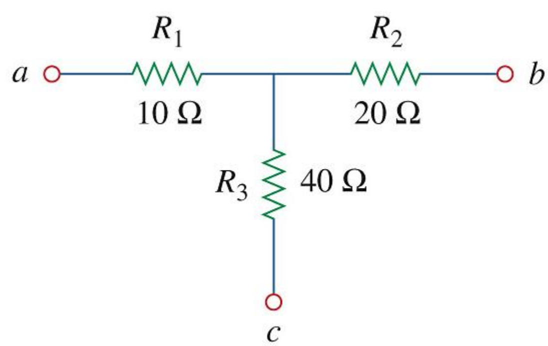


2.7 Wye-Delta Transformations (6)

69

Practice Problem 2.14

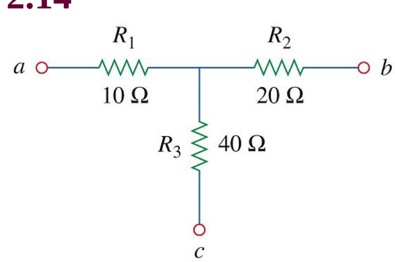
Transform the wye network, in the figure shown below, to a delta network.



2.7 Wye-Delta Transformations (7)

70

Solution for P.P. 2.14



$\mathbf{R_a} = [R_1 R_2 + R_2 R_3 + R_3 R_1] / R_1 = [10x20 + 20x40 + 40x10]/10 =$ **<u>140 ohms</u>**

$\mathbf{R_b} = [R_1 R_2 + R_2 R_3 + R_3 R_1] / R_2 = 1400/20 =$ **<u>70 ohms</u>**

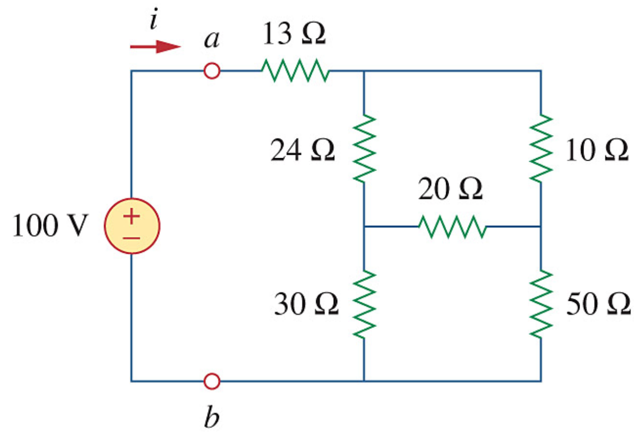
$\mathbf{R_c} = [R_1 R_2 + R_2 R_3 + R_3 R_1] / R_3 = 1400/40 =$ **<u>35 ohms</u>**

2.7 Wye-Delta Transformations (8)

71

Practice Problem 2.15

For the bridge network in the figure below, find R_{ab} and i.

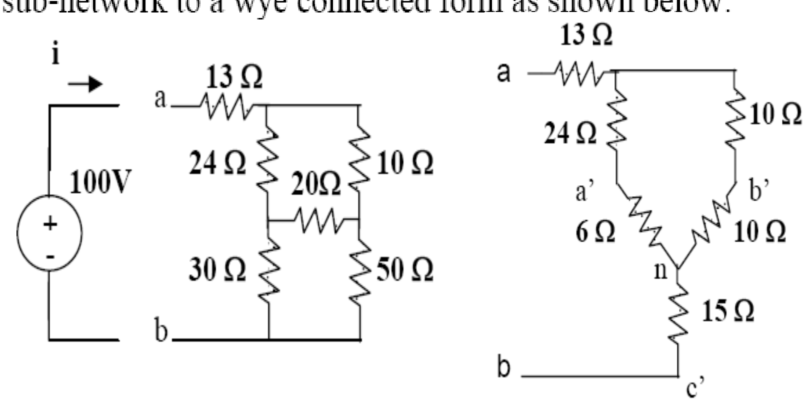


2.7 Wye-Delta Transformations (9)

72

Solution for P.P. 2.15

We first find the equivalent resistance, R. We convert the delta sub-network to a wye connected form as shown below:



2.7 Wye-Delta Transformations (10)

cont. Solution for P.P. 2.15

$R_{a'n}$ = 20x30/[20 + 30 + 50] = 6 ohms

$R_{b'n}$ = 20x50/100 = 10 ohms

$R_{c'n}$ = 30x50/100 = 15 ohms

Thus, R_{ab} = 13 + (24 + 6)||(10 + 10) + 15 = 28 + 30x20/(30 + 20) = **40 ohms.**

i = 100/ R_{ab} = 100/40 = **2.5 amps**