Chapter 5

EMT1150
Introduction to Circuit Analysis

Department of Computer
Engineering Technology

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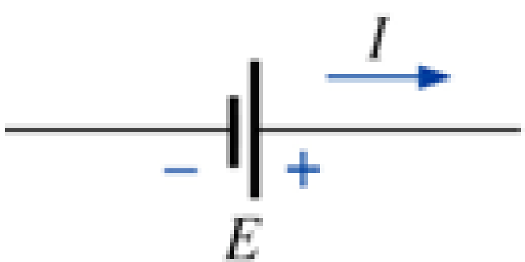
- A positive value for power indicates that power is being absorbed (or consumed by) the circuit element.

- A negative value indicates that power is being extracted from (or generated by) a circuit element (such as a battery).



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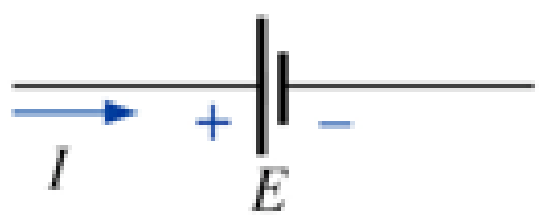

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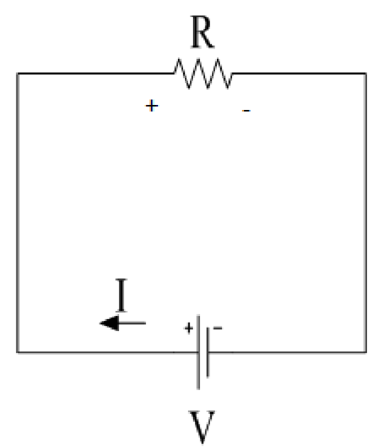
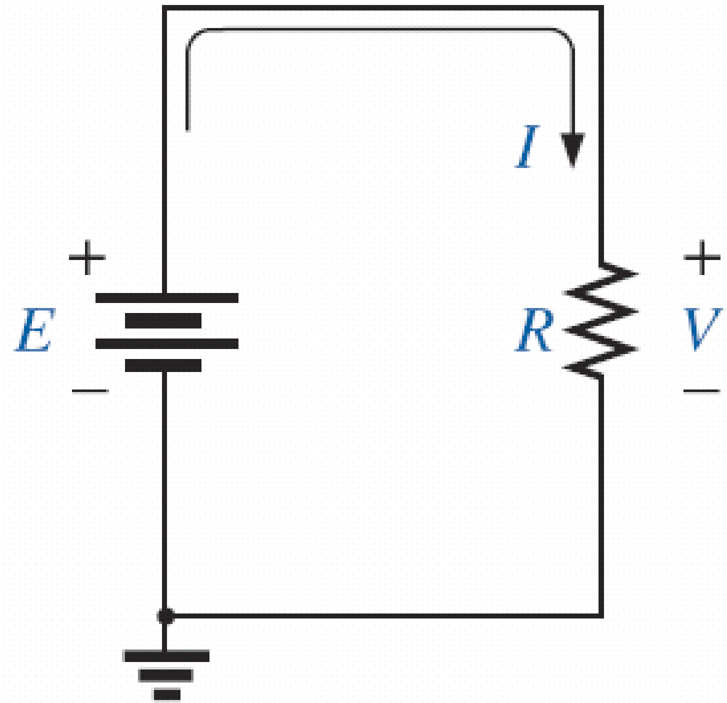


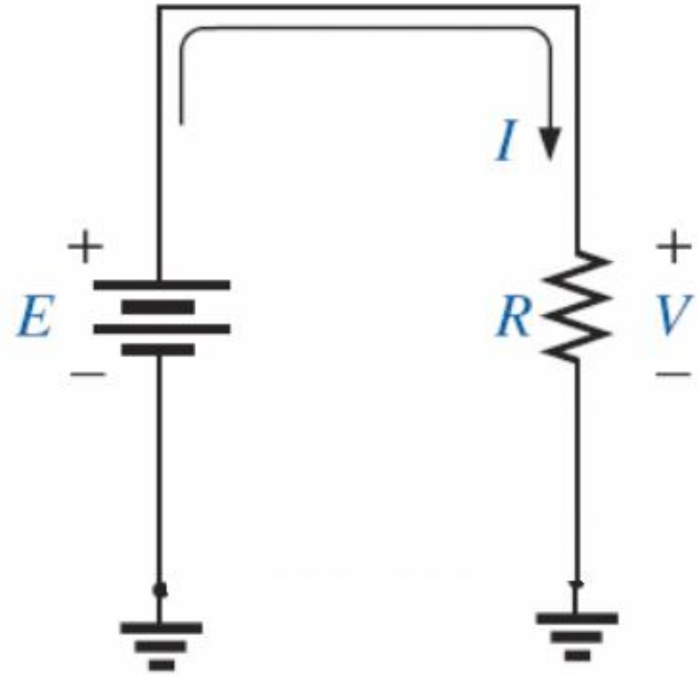
Chapter5 Series DC circuit

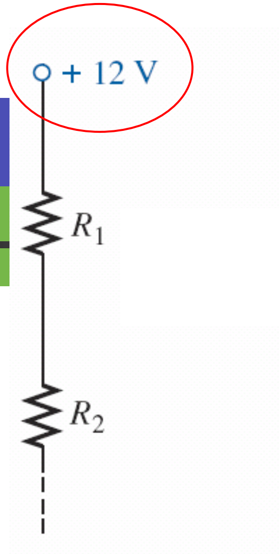
- Symbol and Notations
- Series connection
- Kirchhoff's voltage law
- Voltage source

Symbol

- Symbols we knew
- Ground: electrical and electronic systems are grounded for reference and safety purposes.
- Grounds at different points are the same ground.







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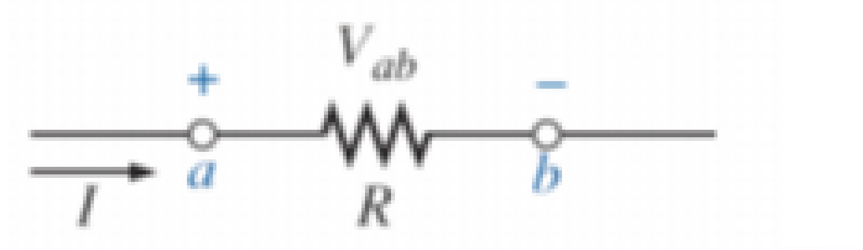
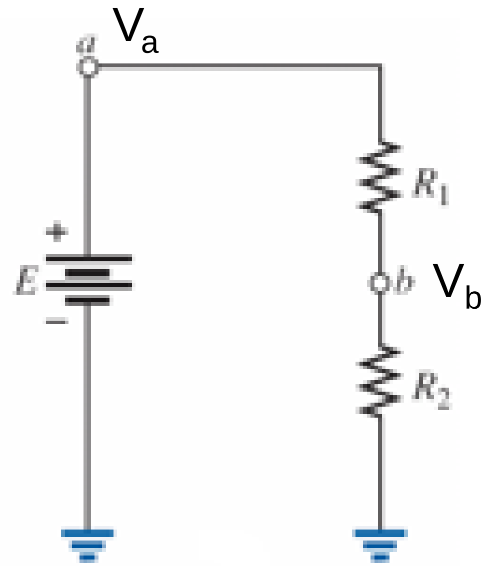


Double-Subscript Notation: the voltage V_{ab} is the voltage at point a with respect to point b

$$V_{ab} = V_a - V_b$$

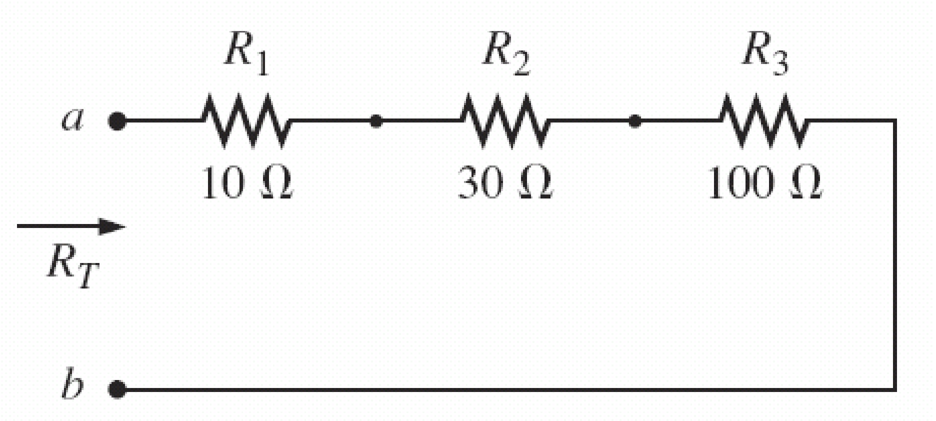


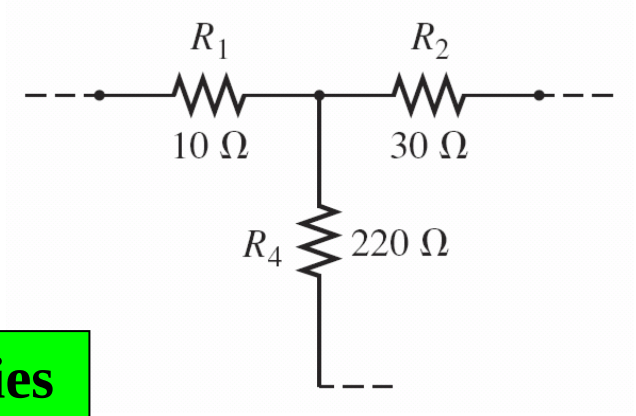
A single-subscript notation can be used that provides the voltage at a point with respect to ground.

Series connection

- Two elements are in series if

1. They have only one terminal in common
2. The common point between the two points is not connected to another current-carrying element.





The current is the same through series elements.

The total resistance of a series circuit is the sum of the resistance levels. In general, to find the total resistance of N resistors in series, the following equation is applied:

$$R_T = R_1 + R_2 + R_3 + \cdot\cdot\cdot + R_N \quad \text{(ohms, }\Omega\text{)}$$

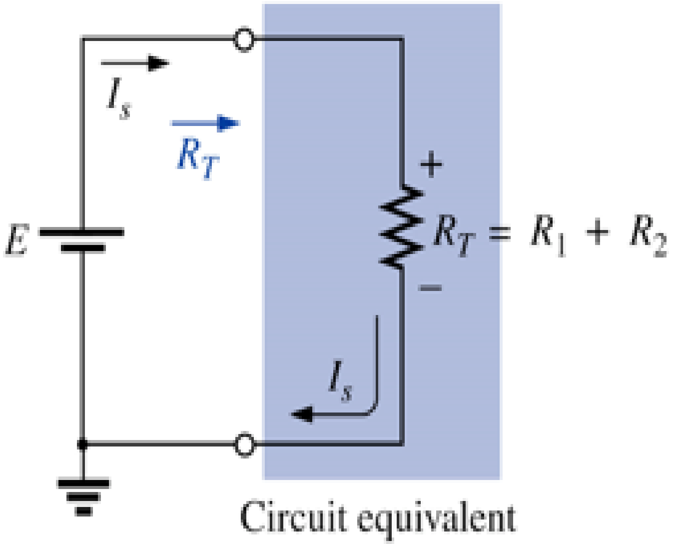
$$I_s = \frac{E}{R_T} \quad \text{(amperes, A)}$$

$$V_1 = IR_1,\ V_2 = IR_2,\ V_3 = IR_3,\ \cdot\cdot\cdot V_N = IR_N \quad \text{(volts, V)}$$

$$P_1 = V_1 I_1 = I_1^2 R_1 = \frac{V_1^2}{R_1} \quad \text{(watts, W)}$$

$$P_{consumed} = P_1 + P_2 + P_3 + \cdot\cdot\cdot + P_N$$

$$P_{generated} = EI \quad \text{(watts, W)}$$



In any closed electric circuit, the amount of power that is generated must be equal to the amount that is absorbed.

$$P_{gen} = P_{con}$$

Power Distribution in Series Circuit

- In any electrical system, the power applied will equal the power dissipated or absorbed.
- For any series circuit, such as that in Fig. 5.21, ***the power applied by the dc supply must equal that dissipated by the resistive elements.***
- In a series configuration, maximum power is delivered to the largest resistor.

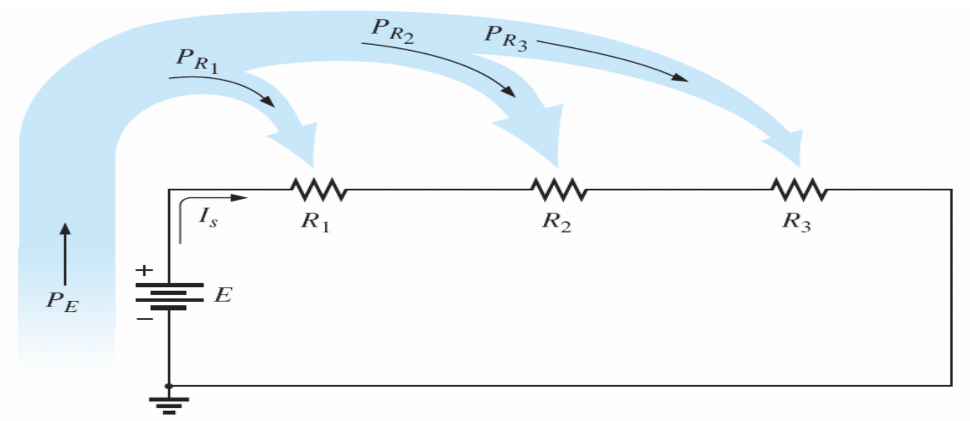


FIG. 5.21 *Power distribution in a series circuit.*

- In equation form,

$$P_E = P_{R_1} + P_{R_2} + P_{R_3}$$

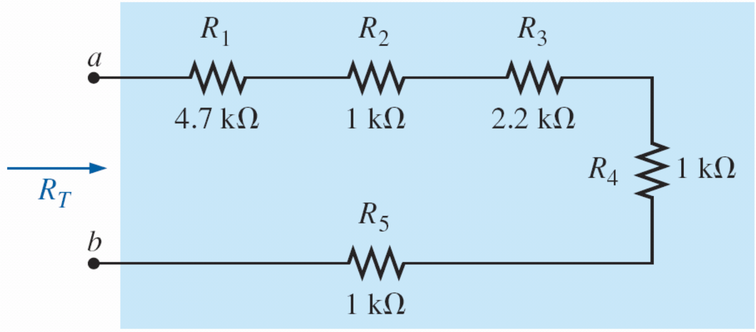
- The power delivered by the supply:

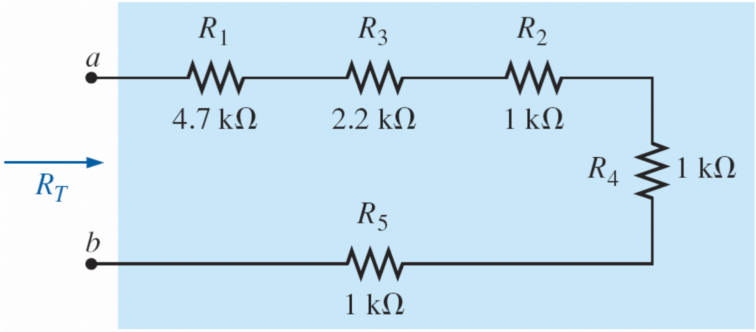
$$P_E = EI_S \qquad \text{(watts, W)}$$

- The power dissipated by R_1

$$P_1 = V_1 I_1 = I_1^2 R_1 = \frac{V_1^2}{R_1} \qquad \text{(watts, W)}$$

Exp1. Find the total resistance of figure.





$R_T = R_1+R_2+R_3+R_4+R_5 = 4.7k\Omega + 1k\Omega + 2.2k\Omega + 1k\Omega + 1k\Omega$

$= 9.9\ (k\Omega)$

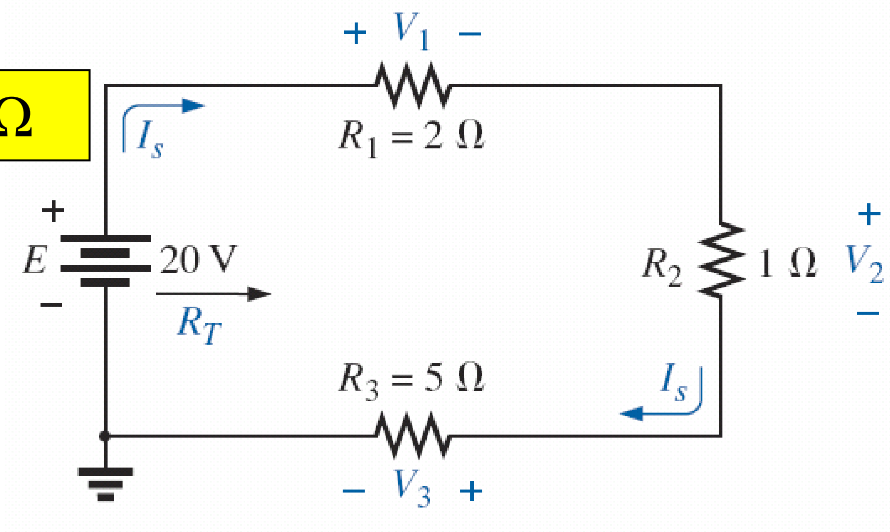
Exp2. (a). Find the total resistance for the series circuit in the Figure.

(b). Calculate the source current I_s.

(c). Calculate the voltages V_1, V_2, and V_3.

(d). Calculate the power dissipated by R_1, R_2, and R_3.

(e). Determine the power delivered by the source, and compare it to the sum of the power levels of part (d).



(a) $R_T = R_1 + R_2 + R_3 = 2\Omega + 1\Omega + 5\Omega = 8\Omega$

$$(b) I_s = \frac{E}{R_T} = \frac{20V}{8\Omega} = 2.5A$$

(c) $V_1 = IR_1 = (2.5A)(2\Omega) = 5V$

$V_2 = IR_2 = (2.5A)(1\Omega) = 2.5V$

$V_3 = IR_3 = (2.5A)(5\Omega) = 12.5V$

(d) $P_1 = V_1 I_s = (5V)(2.5A) = 12.5W$

$P_2 = V_2 I_s = (2.5V)(2.5A) = 6.25\ W$

$P_3 = V_3 I_s = (12.5V)(2.5A) = 31.25\ W$

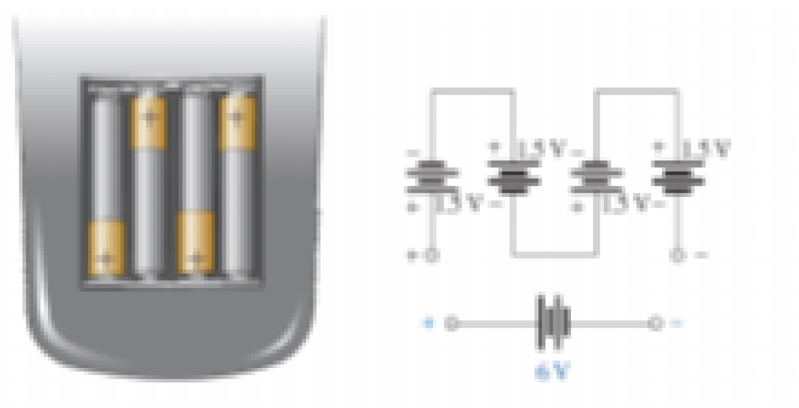
(e) $P_{del} = EI = (20V)(2.5A) = 50W$

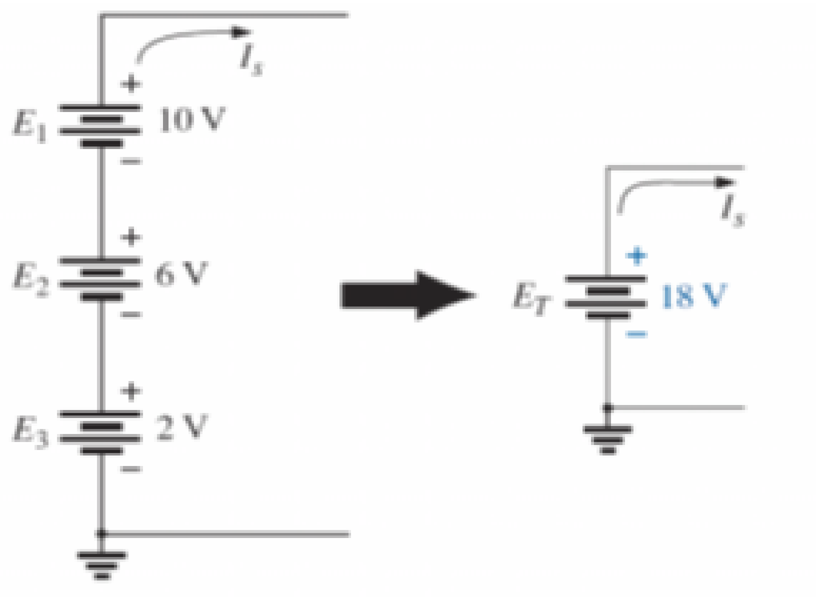
$P_{del} = P_1 + P_2 + P_3$

$50W = 12.5W + 6.25W + 31.25W$

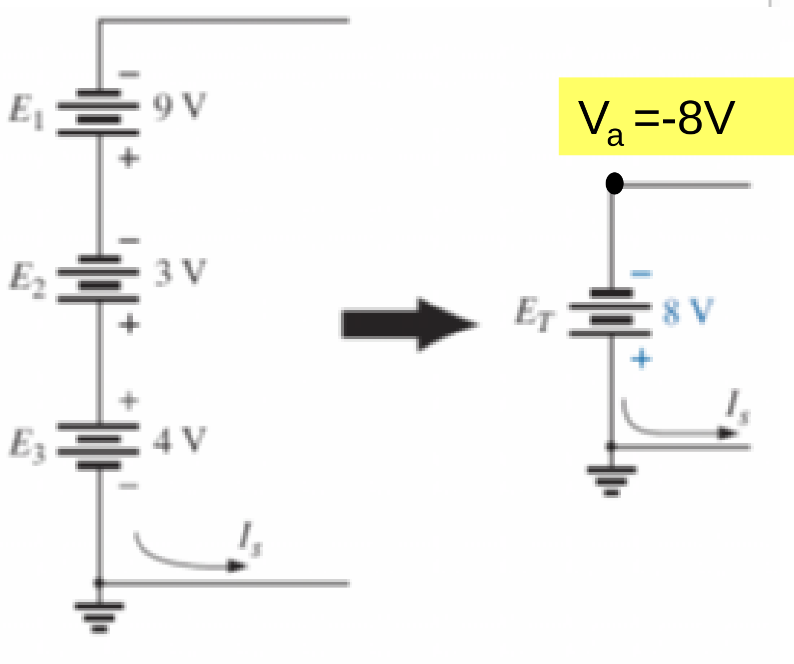
Voltage source in series

- Voltage sources can be connected in series to increase or decrease the total voltage applied to a system.
- The net voltage is determined simply by summing the sources with the same polarity and subtracting the total of the sources with the opposite polarity.
- The net polarity is the polarity of the larger sum.





$$E_T = E_1 + E_2 + E_3 = 10V + 6V + 2V = 18V$$



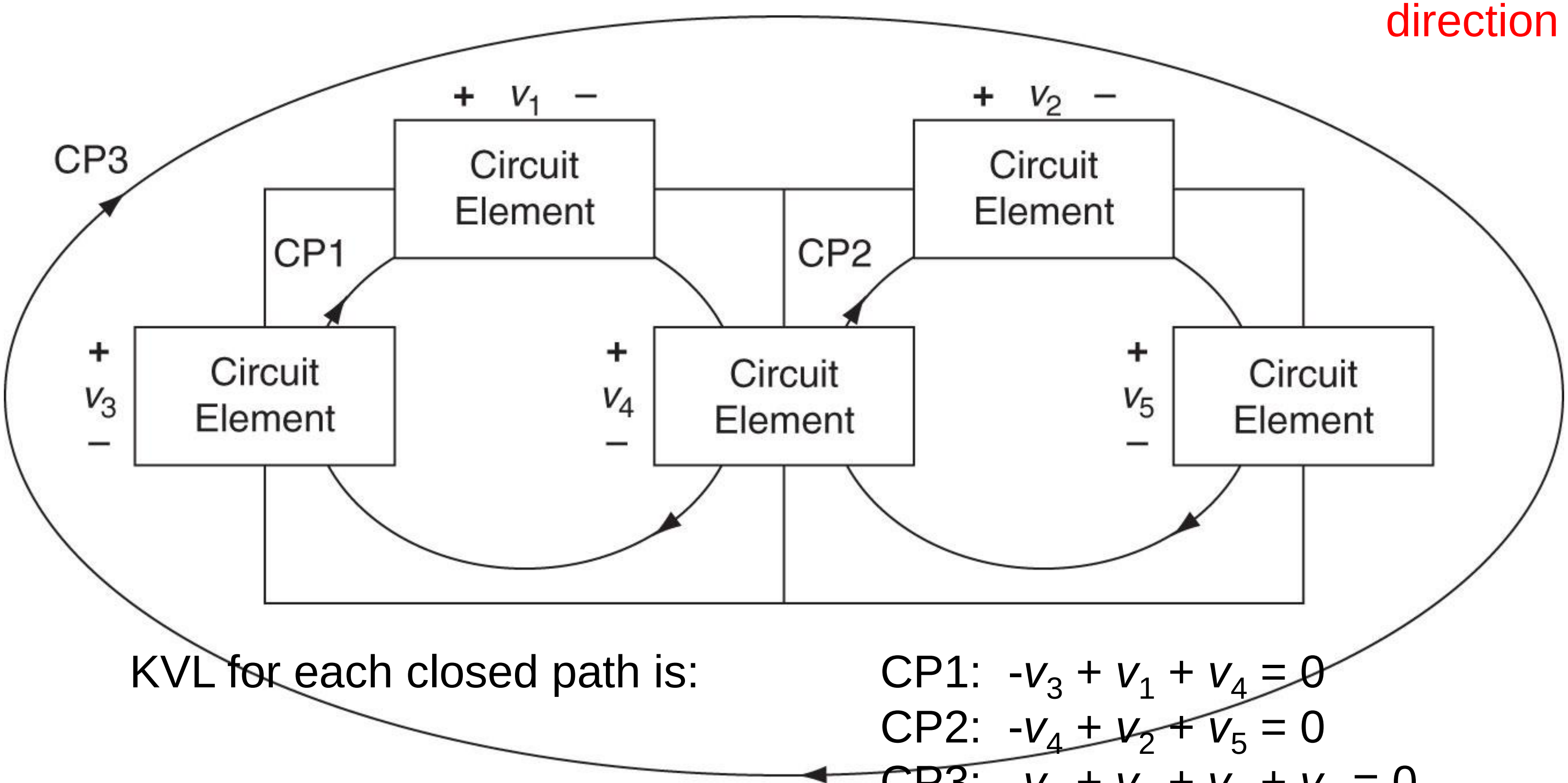
(b)

$$E_T = E_1 + E_2 - E_3 = 9V + 3V - 4V = 8V$$

• We can define the following terms for circuits:

Node: a point at which two or more circuit elements have a common connection.
Branch: a circuit element or connected group of elements; a branch usually connects nodes together.
Path: a connected group of circuit elements in which none is repeated.
Closed path: a path that starts and ends at the same node.

Clock-wise direction



KVL for each closed path is:

CP1: $-v_3 + v_1 + v_4 = 0$
CP2: $-v_4 + v_2 + v_5 = 0$
CP3: $-v_3 + v_1 + v_2 + v_5 = 0$

Kirchhoff's voltage law

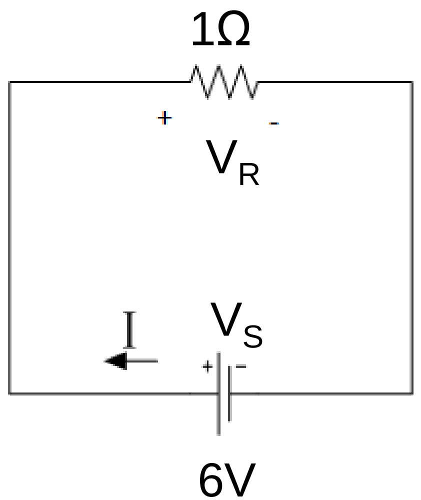
Kirchhoff's voltage law (KVL) states that algebraic sum of the potential rises and drops around a closed path (or closed loop) is zero:

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

where $v_n(t)$ stands for a voltage drop, and there are N voltage drops assigned around the closed path.

A **closed path/loop** is any continuous path that leaves a point in one direction and returns to that same point from another direction without leaving the circuit.

The sign for each voltage change is the first sign encountered when moving around the closed path.



$V_R - V_S = 0$

6-6=0

Three ways to write KVL equations

- The sign for each voltage change is the first sign encountered when moving around the closed path.

$$-E+V_1+V_2=0$$

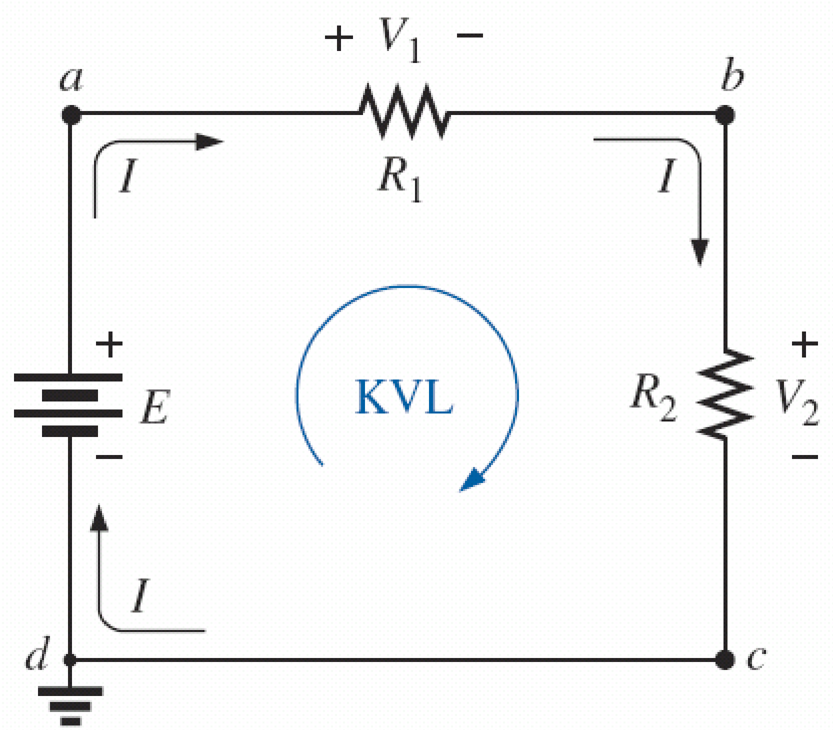
- Give positive sign when proceed from negative to positive potential, give negative sign wen proceed from positive to negative potential.

$$E- V_1 - V_2=0$$

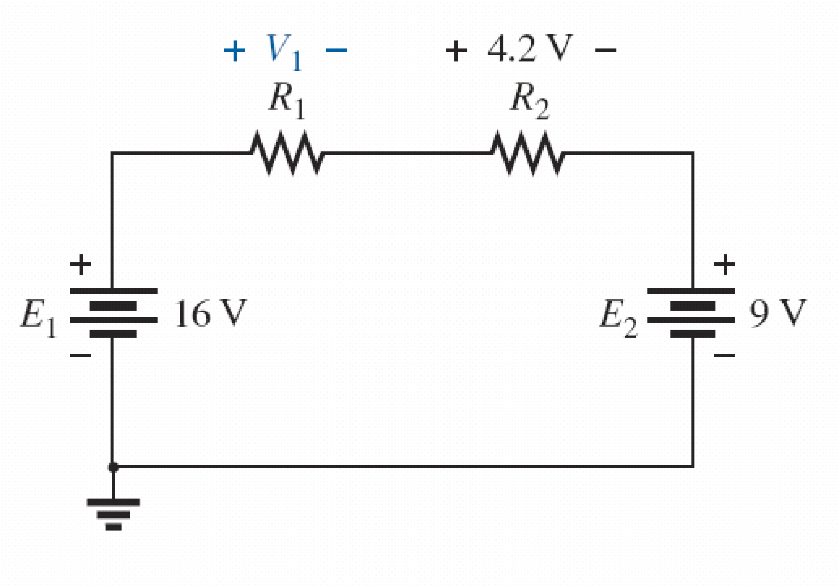
- The sum of voltage rises around a closed path will equal to the sum

  of voltage drops.

$$E = V_1 + V_2$$



Exp3: Determine the unknown voltages for the networks.



$-E_1 + V_1 + V_2 + E_2 = 0$

$V_1 = E_1 - V_2 - E_2$
$= 16V - 4.2V - 9V$
$= 2.8V$

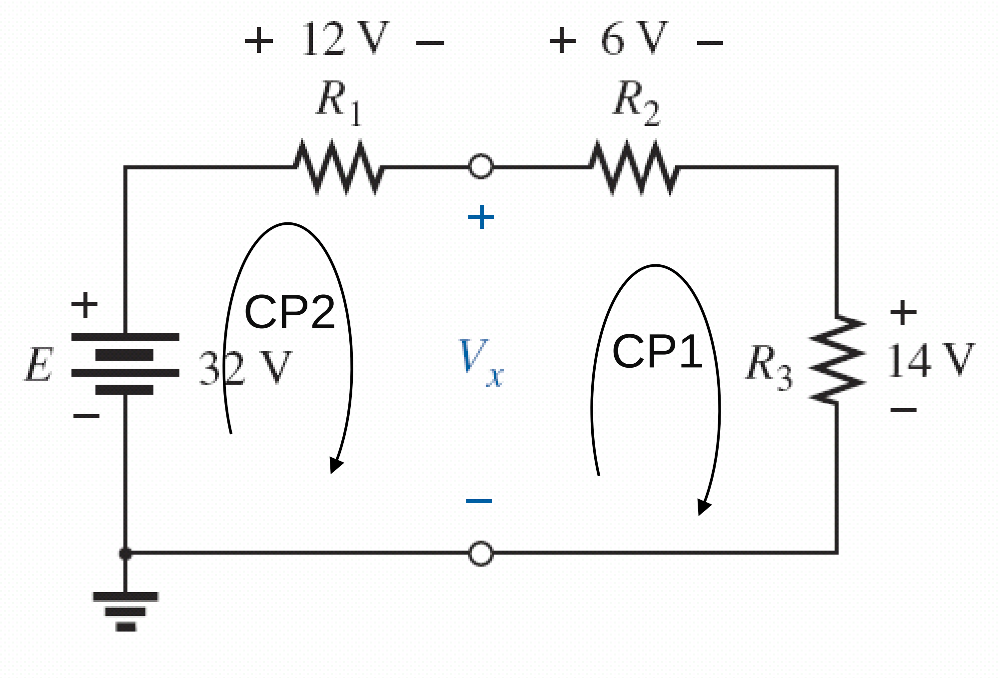
$E_1 - V_1 - V_2 - E_2 = 0$

$V_1 = E_1 - V_2 - E_2$
$= 16V - 4.2V - 9V$
$= 2.8V$

$E_1 = V_1 + V_2 + E_2 = 0$

$V_1 = E_1 - V_2 - E_2$
$= 16V - 4.2V - 9V$
$= 2.8V$

Exp4: Determine the unknown voltages for the networks.



$E - V_1 - V_x = 0$

$V_x = E - V_1$
$= 32V - 12V$
$= 20V$

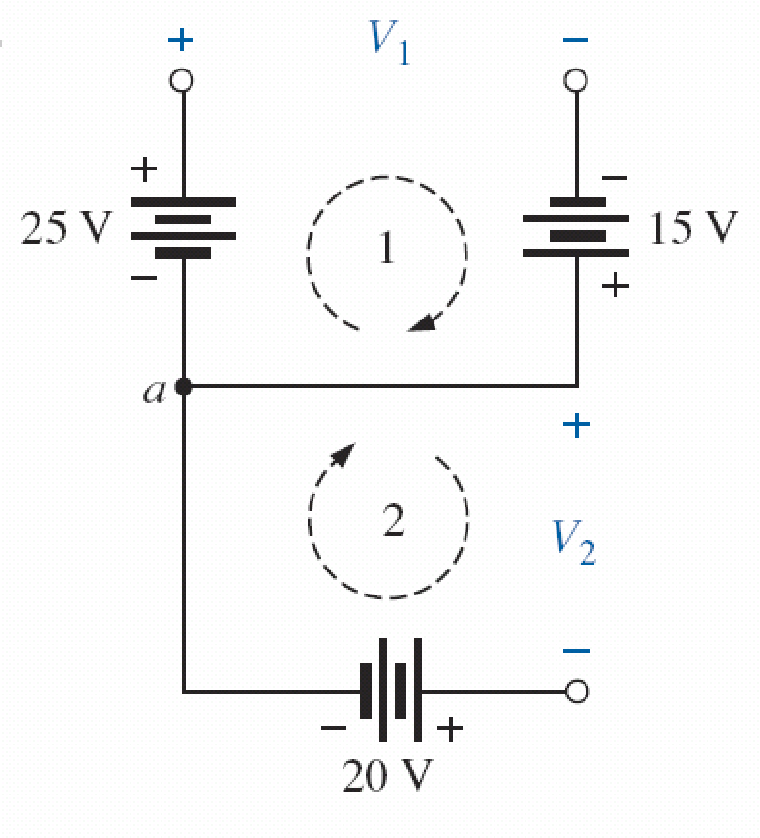
Exp5: Determine the unknown voltages for the networks.

KVL @ CP1

$$-25V + V_1 - 15V = 0$$
$$V_1 = 40V$$

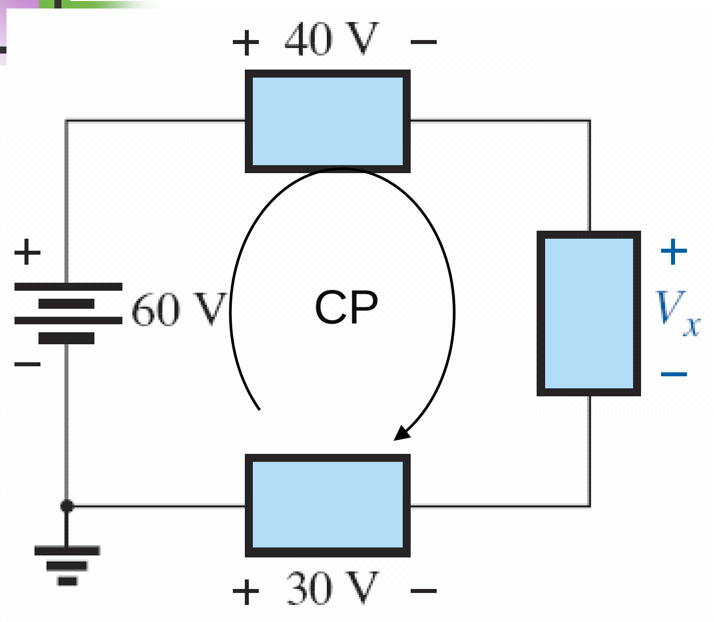
KVL @ CP2

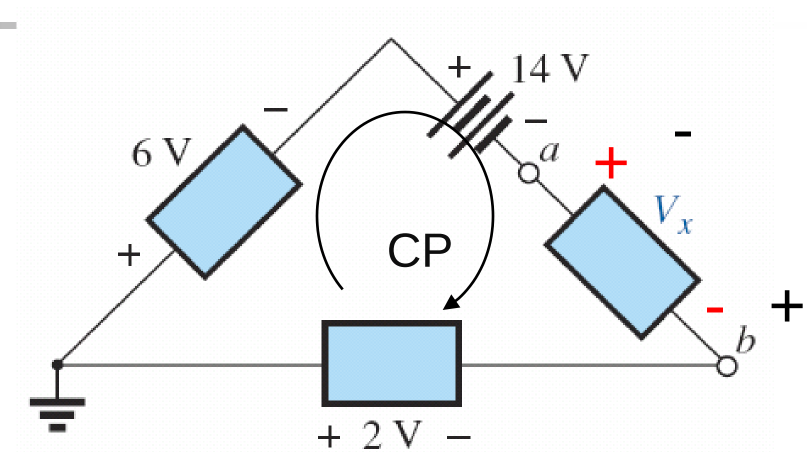
$$V_2 + 20V = 0$$
$$V_2 = -20V$$



No current, but KVL still apply.

Exp9: Determine the unknown voltages for the networks.





$$-60V + 40V + V_x - 30V = 0$$

$$V_x = 60V - 40V + 30V$$
$$= \mathbf{50V}$$

$$6V + 14V + V_x - 2V = 0$$

$$V_x = -6V - 14V + 2V$$
$$= -\mathbf{18V}$$

$$6V + 14V - V_x - 2V = 0$$

$$V_x = 6V + 14V - 2V$$
$$= \mathbf{18V}$$

Exp6: a. Determine V_2 using Kirchhoff's voltage law.

b. Determine I.

c. Find R_1 and R_2.

a. KVL @ CP

$$E - V_3 - V_2 - V_1 = 0$$

or

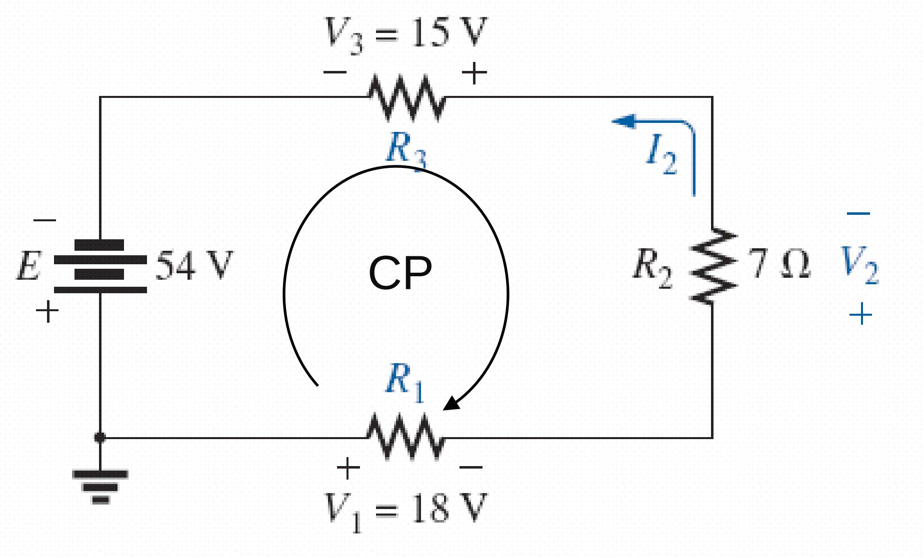
$$E = V_1 + V_2 + V_3$$

$$V_2 = E - V_1 - V_3 = 54V - 18V - 15\ V = 21V$$

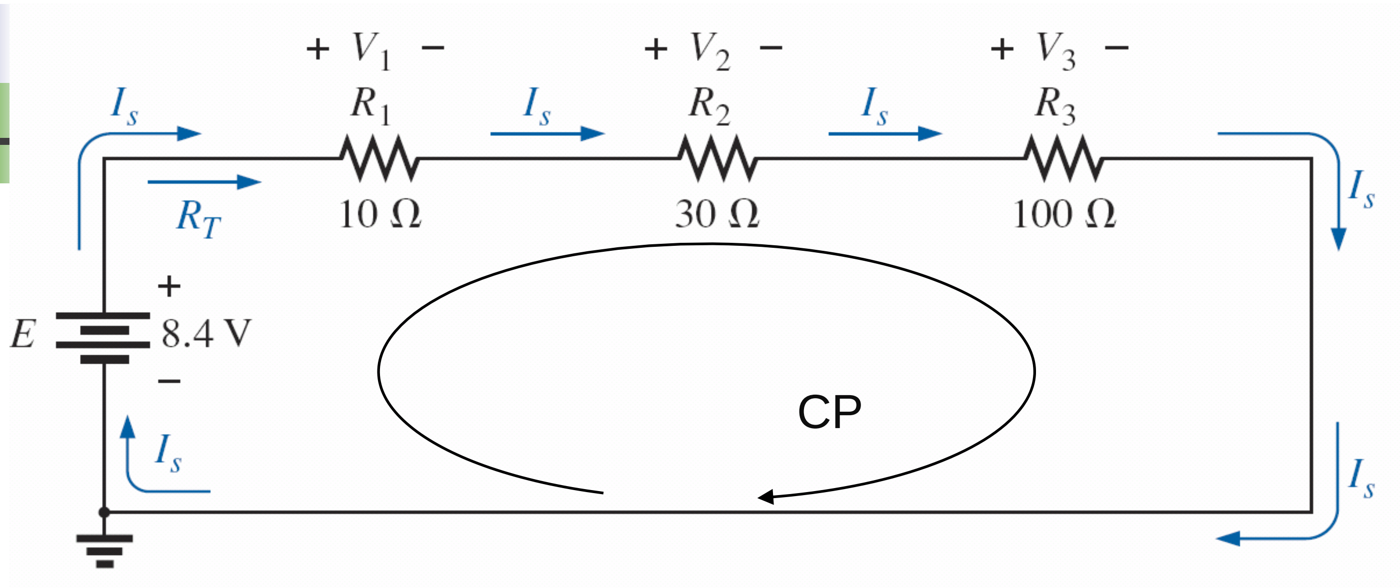
b. $$I = \frac{V_2}{R_2} = \frac{21\ V}{7\ \Omega} = 3\ A$$

c. $$R_1 = \frac{V_1}{I} = \frac{18\ V}{3\ A} = 6\,\Omega$$

$$R_3 = \frac{V_3}{I} = \frac{15\ V}{3\ A} = 5\,\Omega$$



Apply KVL to series resistor network to find equivalent resistance



KVL @ the network

$$-E + V_1 + V_2 + V_3 = 0$$

Ohm's law to each resistor

$$-E + IR_1 + IR_2 + IR_3 = 0 \qquad E = I(R_1 + R_2 + R_3)$$

$$R_T = \frac{E}{I} = R_1 + R_2 + R_3$$

Voltage Divider Rule

- This rule is used to calculate the voltage across any single resistor connected in a series of resistors.
  - Recall the equivalent resistance for resistors in series:

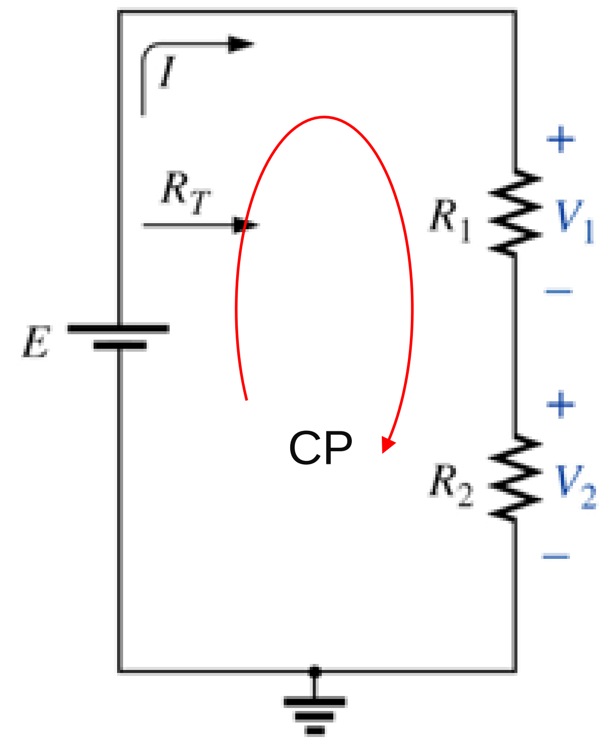
$$R_T = \frac{E}{I} = R_1 + R_2$$

- Consider finding V_2 in the series circuit shown below:

$$V_2 = IR_2$$

$$I = \frac{E}{R_T} = \frac{E}{R_1 + R_2}$$

$$V_2 = IR_2 = \left(\frac{E}{R_1 + R_2}\right) R_2 = E\left(\frac{R_2}{R_1 + R_2}\right)$$



- This same analysis can be used to find V_1:

$$V_1 = E\left(\frac{R_1}{R_1 + R_2}\right)$$

R_1 as a fraction of the total resistance in the series

- In general, if a circuit contains *N* resistors in series, the voltage across any one of the resistors R_i is:

$$V_i = E\left(\frac{R_i}{R_1 + R_2 + \cdots R_N}\right)$$

Note: we don't need to know the current, I only need to know total input voltage.

In other words, in a series resistive circuit, the larger the resistance, the more of the applied voltage it will capture.

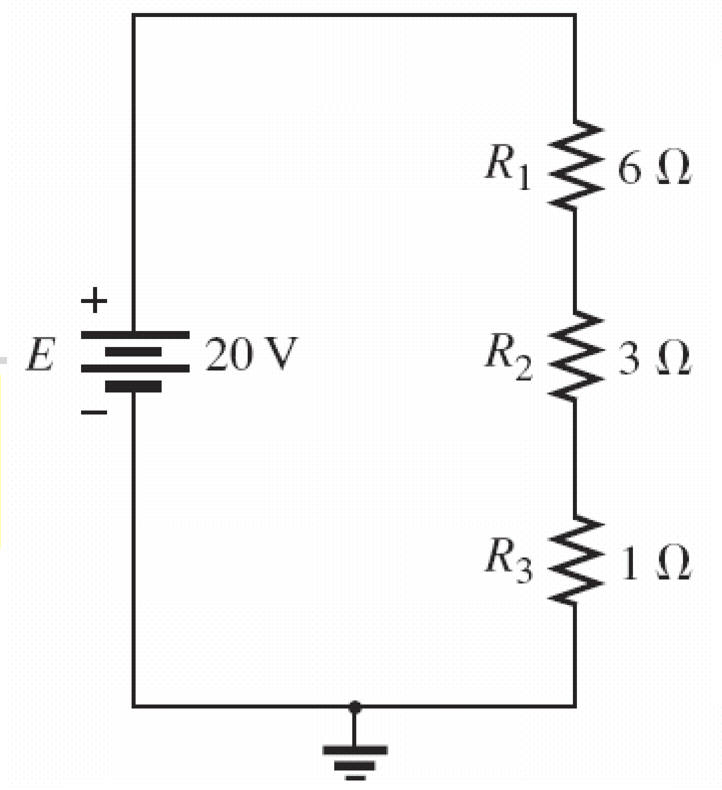
$$\frac{V_1}{V_2} = \frac{R_1}{R_2}$$

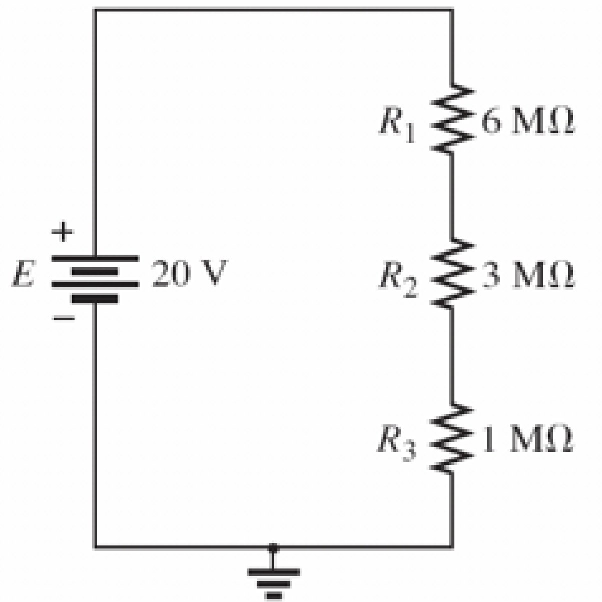
Exp11: Determine V_1 , V_2 and V_3.

$$V_1 = 20V\left(\frac{6\Omega}{6\Omega + 3\Omega + 1\Omega}\right) = 12(V)$$

$$V_2 = 20V\left(\frac{3\Omega}{6\Omega + 3\Omega + 1\Omega}\right) = 6(V)$$

$$V_3 = 20V\left(\frac{1\Omega}{6\Omega + 3\Omega + 1\Omega}\right) = 2(V)$$

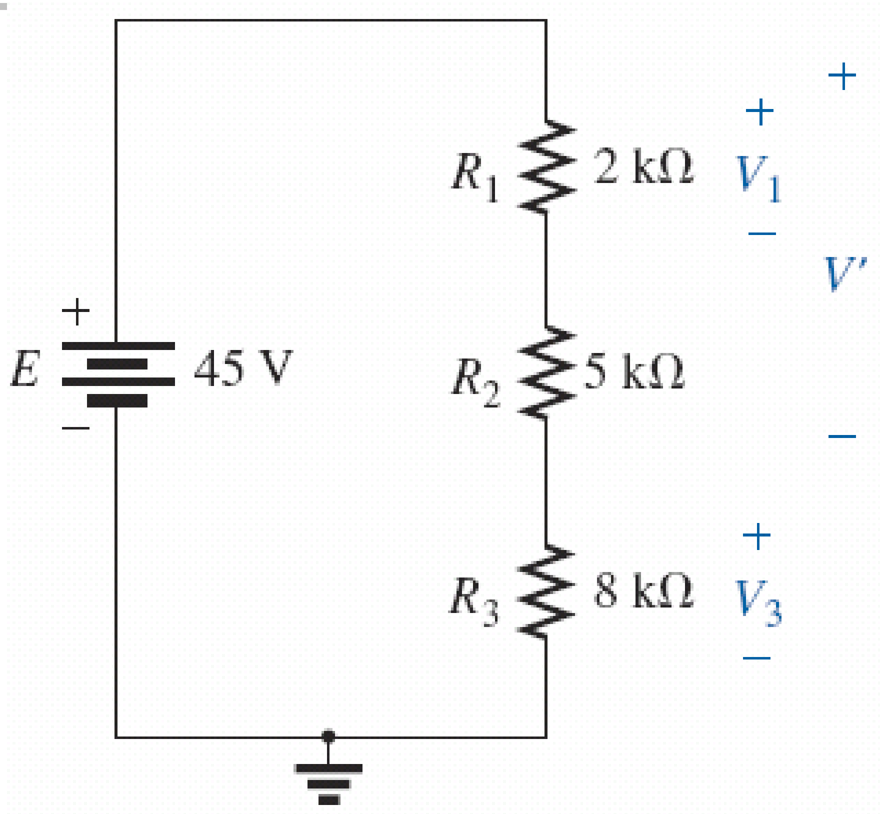




Exp12: Using the voltage divider rule, determine the voltages V_1, V_3 and V´ for the series circuit.

$$V_1 = \frac{R_1 E}{R_T} = \frac{(2\,k\Omega)(45\,V)}{2\,k\Omega + 5\,k\Omega + 8\,k\Omega} = \frac{(2\,k\Omega)(45\,V)}{15\,k\Omega} = \frac{(2\times10^3\,\Omega)(45V)}{15\times10^3\,\Omega} = \frac{90\,V}{15\,\Omega} = 6\,V$$

$$V_3 = \frac{R_3 E}{R_T} = \frac{(8\,k\Omega)(45\,V)}{2\,k\Omega + 5\,k\Omega + 8\,k\Omega} = \frac{(8\,k\Omega)(45\,V)}{15\,k\Omega} = \frac{(8\times10^3\,\Omega)(45V)}{15\times10^3\,\Omega} = \frac{360\,V}{15\,\Omega} = 24\,V$$



$$V' = \frac{R' E}{R_T} = \frac{(2\,k\Omega + 5\,k\Omega)(45V)}{15\,k\Omega} = \frac{(7\,k\Omega)(45V)}{15\,k\Omega} = 21\,V$$

Exp13: Find the resistor values of R_1 and R_2 to have $V_{R1} = 4V_{R2}$.

$$R_T = \frac{E}{I} = \frac{20V}{4\,mA} = 5\,k\Omega$$

$$Since\; V_{R1} = 4V_{R2},$$

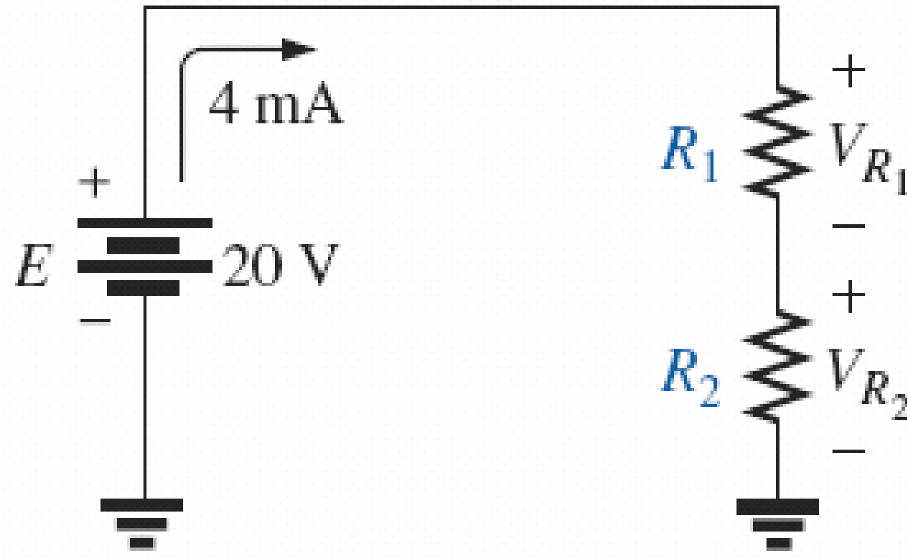
$$R_1 = 4R_2$$

$$Thus \quad R_T = R_1 + R_2 = 4R_2 + R_2 = 5R_2$$

$$and \quad 5R_2 = 5\,k\Omega$$

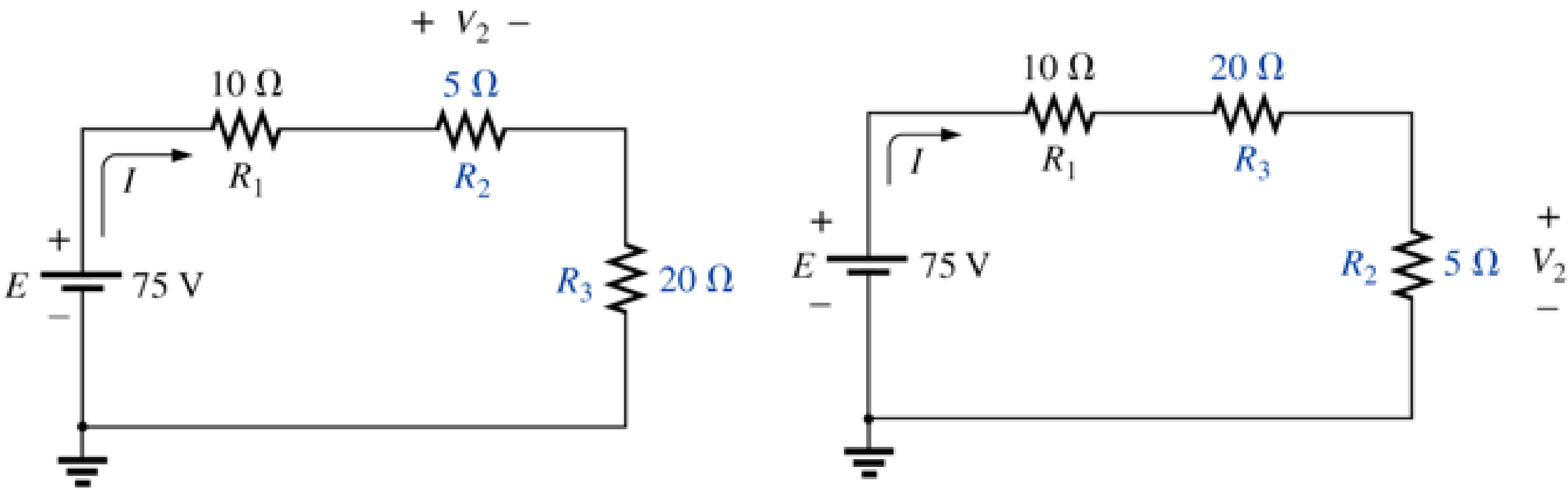
$$R_2 = 1\,k\Omega$$

$$and \quad R_1 = 4R_2 = 4\,k\Omega$$

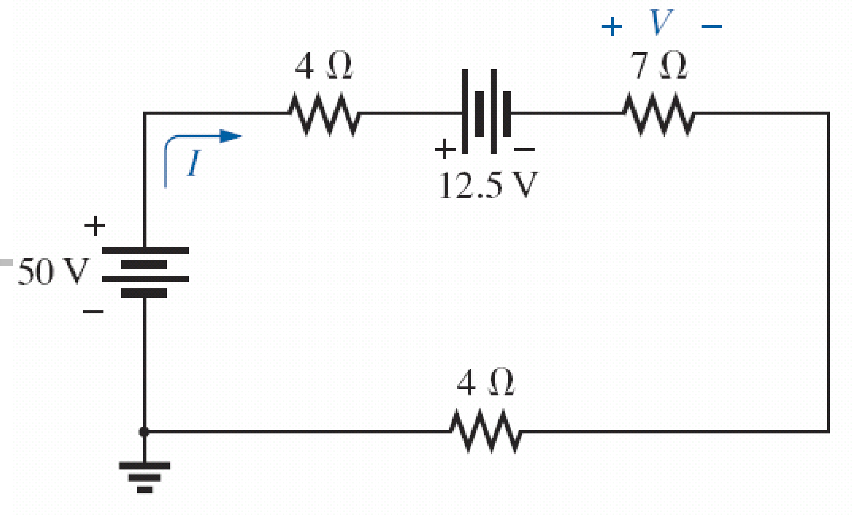


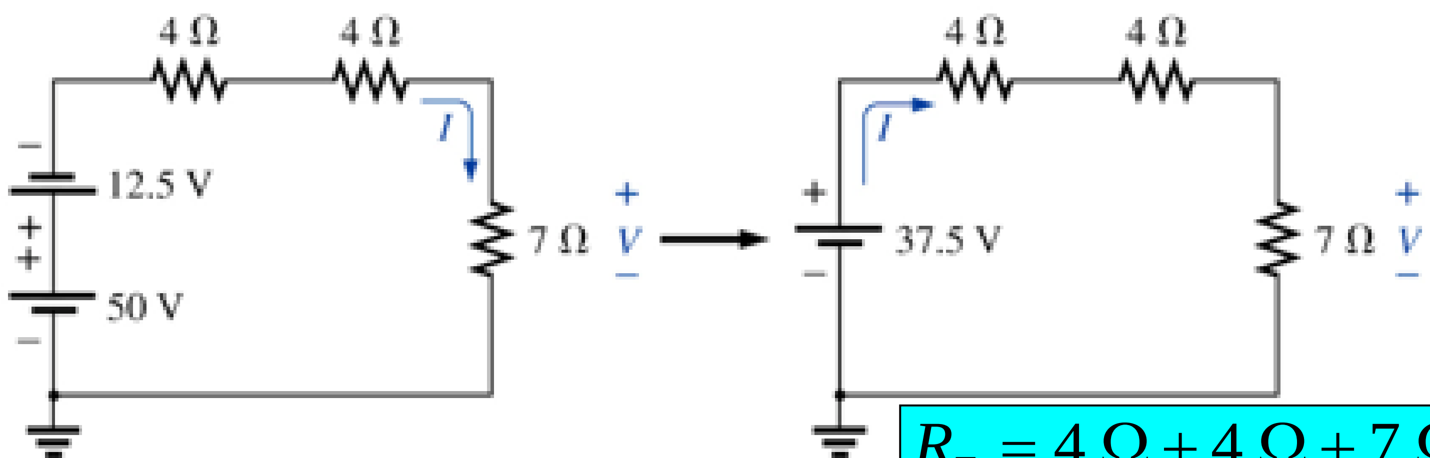
Interchanging Series Elements

- The elements of a series circuit can be interchanged without affecting the total resistance, current, or power to each element.



Exp14: Determine I and the voltage across the 7-Ω resistor





$$R_T = 4\,\Omega + 4\,\Omega + 7\,\Omega = 15\,\Omega$$

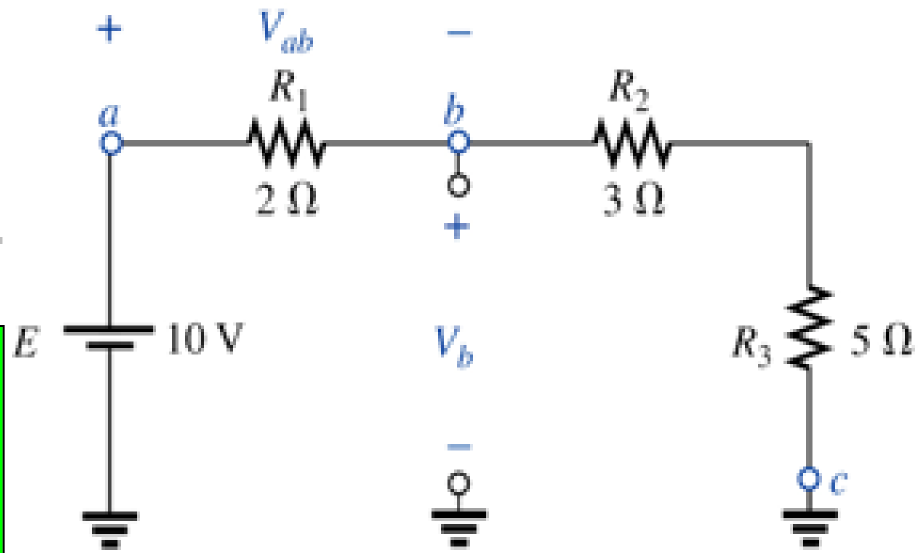
$$I = \frac{E}{R_T} = \frac{37.5\,V}{15\,\Omega} = 2.5\,A$$

$$V_{7\,\Omega} = I\,R = (2.5\,A)(7\,\Omega) = 17.5\,V$$

Exp15: a. Calculate V_{ab}.

b. Determine V_b.

c. Calculate V_c.



c. V_c = ground potential = 0 V

a. Voltage divider rule:

$$V_{ab} = \frac{R_1 E}{R_T} = \frac{(2\Omega)(10V)}{2\Omega + 3\Omega + 5\Omega} = +2V$$

b. Voltage divider rule:

$$V_b = V_{R_2} + V_{R_3} = \frac{(R_2 + R_3)E}{R_T}$$

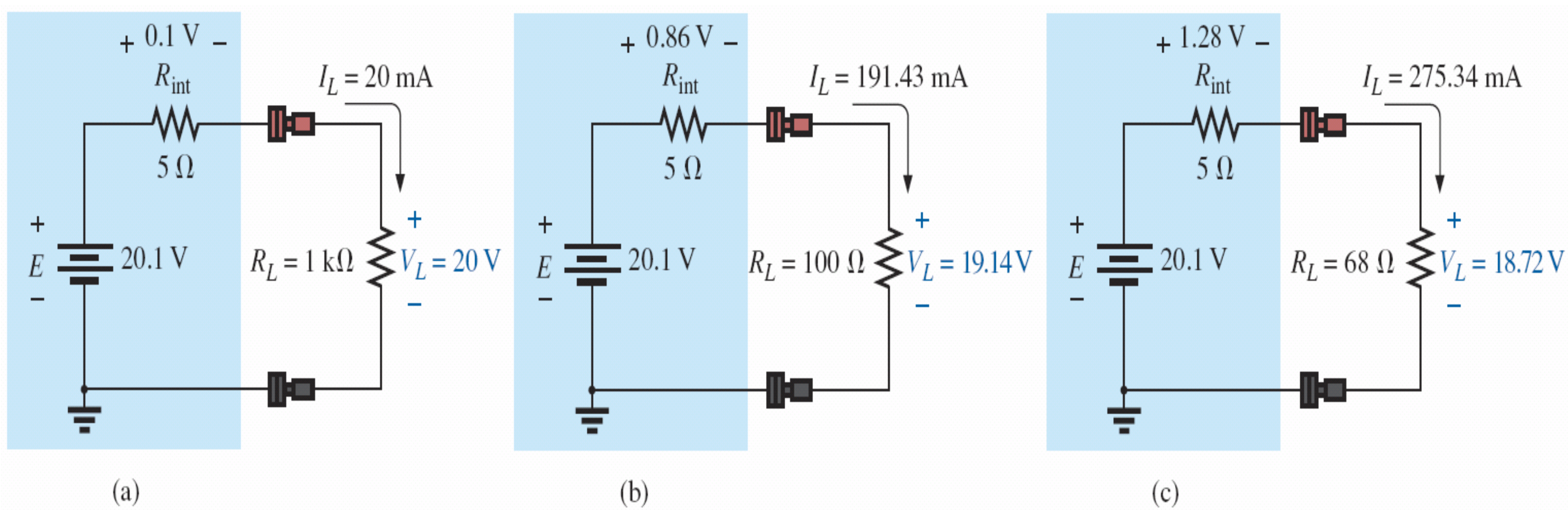
$$= \frac{(3\Omega + 5\Omega)(10V)}{10\Omega} = 8\,V$$

$$or \quad V_b = V_a - V_{ab} = E - V_{ab}$$

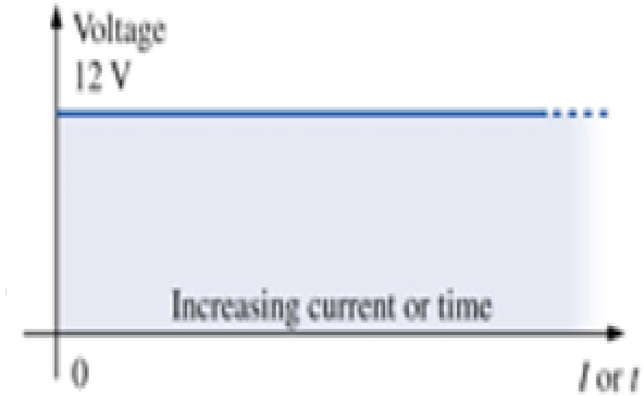
$$= 10V - 2V = 8\,V$$

Ideal Voltage Sources vs. Non-ideal Voltage Sources

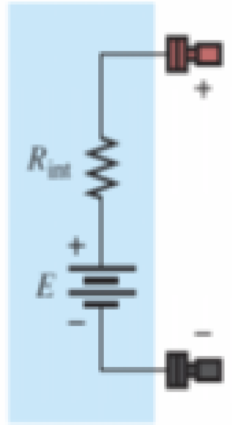
- When you connect any resistors to the power supply, it is called load.
- In the ideal condition, the output of the voltage source is a constant number no matter what load you have.

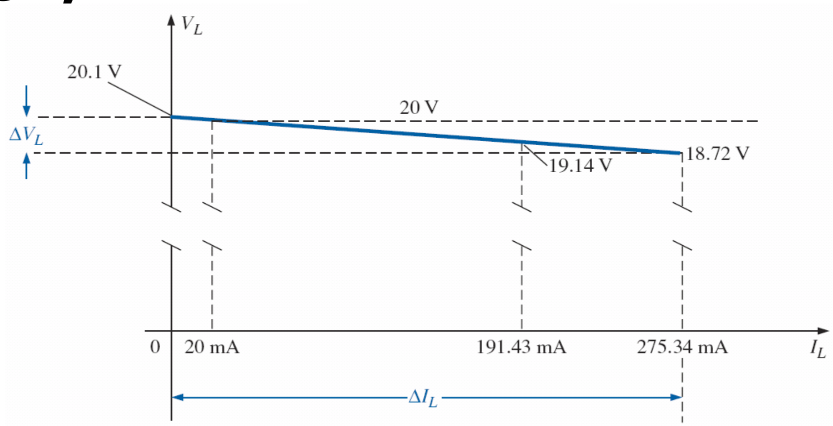


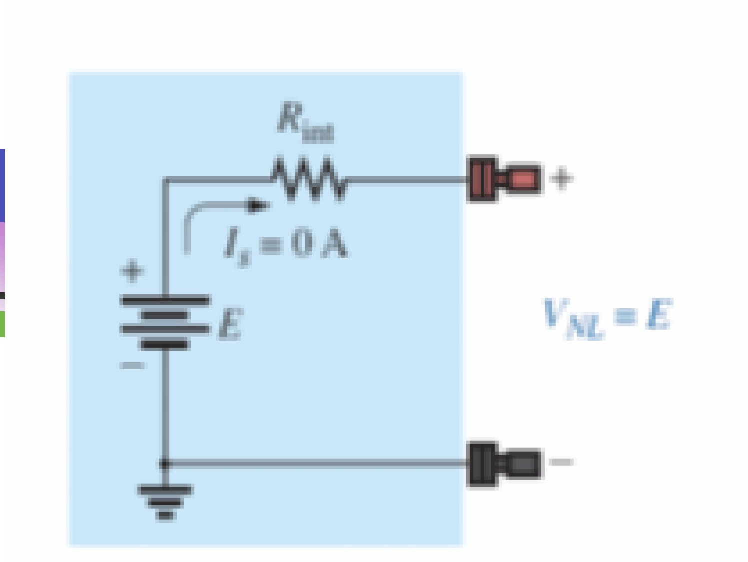
- Ideal voltage source: no internal resistance and an output voltage of *E* volts with no load or full load



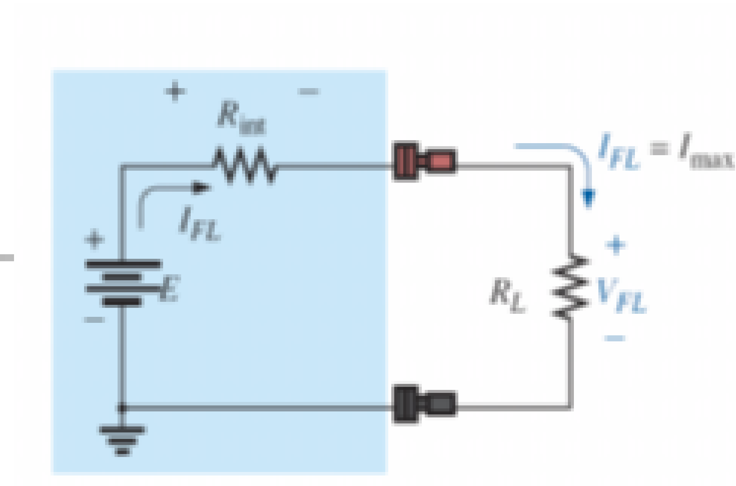
- No-ideal voltage source: every daily used voltage source, such as generator, battery, or laboratory supply, has **internal resistance**



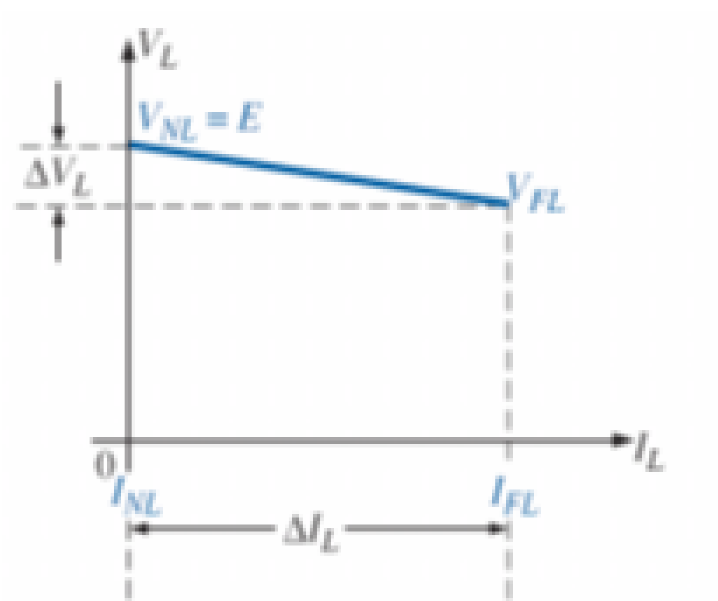




No-load (NL) condition, I_L=0



Full-load (FL) condition, I_L=maximum current the supply can provide in continuous base.



$$R_{int} = \frac{\Delta V_L}{\Delta I_L}$$

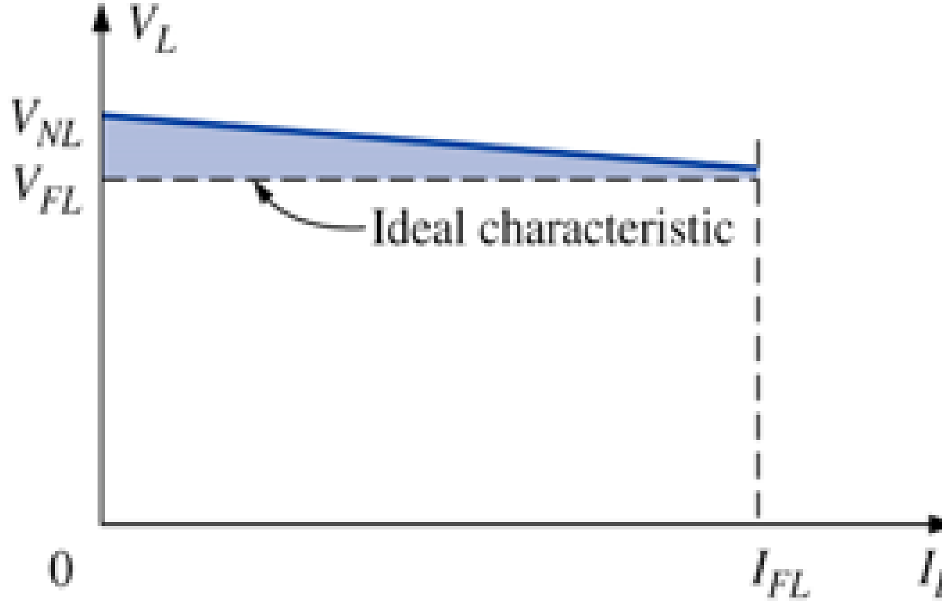
The larger the internal resistance, the steeper is the drop in voltage with an increase in current.

Voltage regulation

$$Voltage\ regulation\ (VR)\% = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$

For ideal conditions, $V_{FL} = V_{NL}$, VR% = 0.

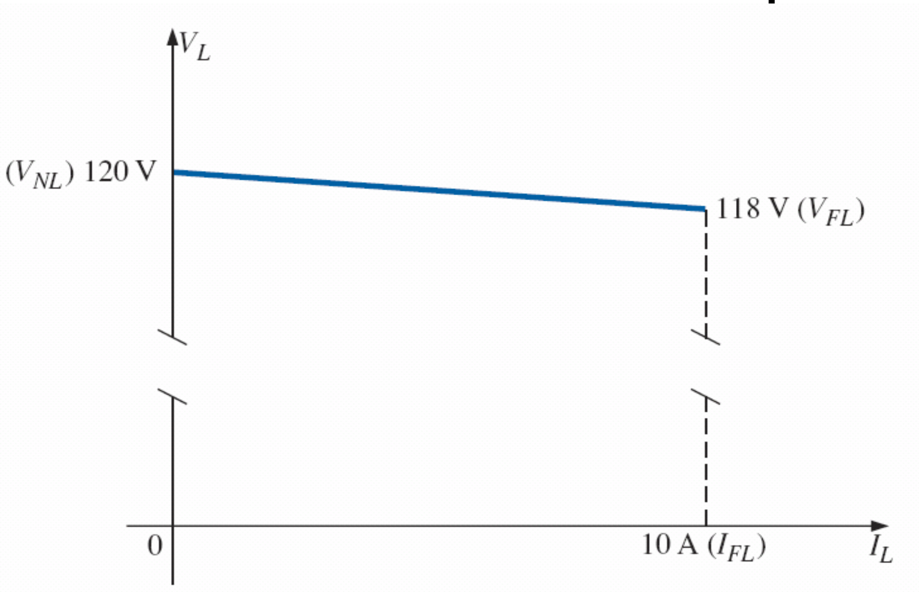
The smaller the voltage regulation, the less the variation in terminal voltage with change in load.



Exp16: a. Calculate the voltage regulation of the supply

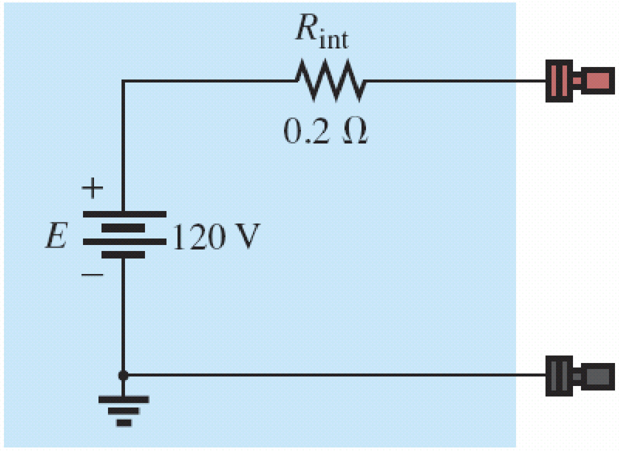
b. Determine the internal resistance.

c. sketch the equivalent circuit for the supply.



$$VR\% = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$

$$= \frac{200\ V - 118V}{118V} \times 100\% = 1.7\%$$



$$R_{int} = \frac{\Delta V_L}{\Delta I_L} = \frac{120V - 118V}{10A - 0A} = 0.2\Omega$$