電路學

Circuits: Engineering Concepts and Analysis of Linear Electric Circuits

李百祺

Course Information

- **時間:** 週五 9:10am-12:10pm
- **地點:** 電二106
- **教科書：** Circuits, by A. Bruce Carlson, Brooks/Cole, 2000.
- **聯絡方式：** 博理館425室 (33663551）
  Email: paichi@cc.ee.ntu.edu.tw
  Web: http://ultrasound.ee.ntu.edu.tw→ 課程 →電路學

Course Content

- Chapter 1: 1.4, 1.5
- Chapter 2: 2.3, 2.4, 2.5
- Chapter 3: 3.2, 3.3
- Chapter 4: 4.1, 4.2, 4.3
- Chapter 5.3
- Chapter 6: 6.1, 6.2, 6.3
- Chapter 7: 7.1, 7.2
- Chapter 9: 9.1, 9.2, 9.3, 9.4
- Chapter 11: 11.1, 11.2, 11.4
- Chapter 13: 13.1, 13.2, 13.3
- Chapter 14: 14.1, 14.2, 14.3

Grading and Homework

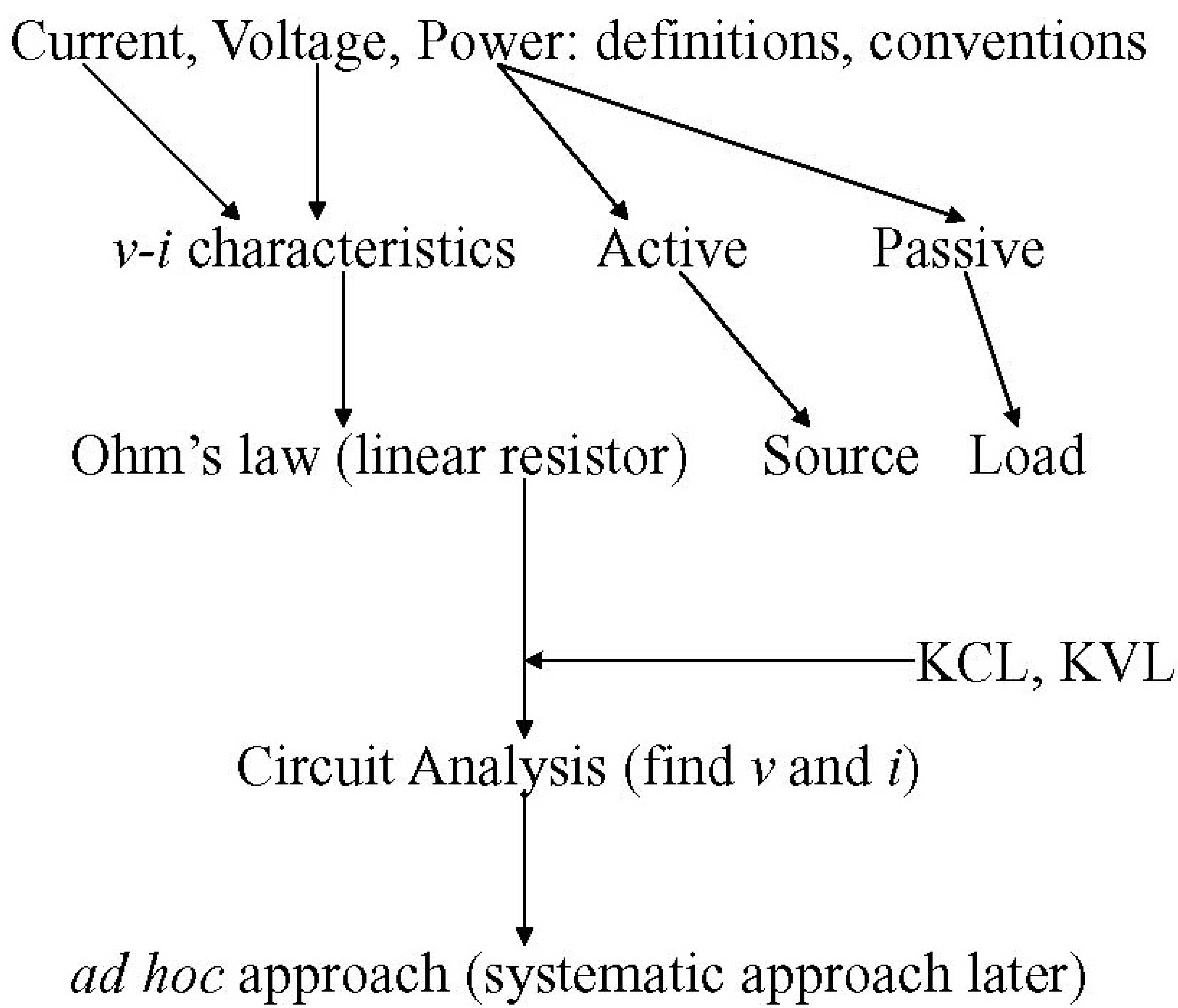
- **考試:** 5次小考及期末考
- **評分方式:** 小考共佔60% (最低分的一次小考不記分)、期末考佔40%
- **習題:** Homework problems will be assigned but not graded. Selected problems will be solved in class.

電路學學什麼？

- 學電路
- 學電路分析
- 學電路分析與設計
- 學線性電路分析與設計
- 學集總 (lumped) 線性電路分析與設計
- 學基本代數分析方法及應用phasor, Fourier transform, Laplace transform 之分析方法

Chapter 1: Circuit Variables and Laws

Chapter 1: Outline



Chapter 1: Circuit Variables and Laws

- Quick review of (self reading):
  - Definition of Current, Voltage, Polarity
  - Definition of Energy, Power, Source and Load
  - Ohm’s law and Resistors
- Kirchhoff’s laws
  - Current (KCL)
  - Voltage (KVL)
- Elementary Circuit Analysis
  - Series and Parallel

Fundamentals

Current: Formal Definition

- Current is the net flow of charges, per time, past an arbitrary "plane" in some kind of electrical device.
- We will only be concerned with the flow of positive charges. A negative charge moving to the right is conceptually the same as a positive charge moving to the left.

$$i = \frac{dq}{dt}$$

Current, typically in Amperes [A]

Charge, typically in Coulombs [C]

Time, typically in seconds [s]

The Ampere

- The unit of current is the Ampere, which is a flow of 1 Coulomb of charge per second, i.e.:

$$1[A] = 1[Coul/sec]$$

- Current is defined in terms of the flow of <u>positive</u> charges.

One coulomb of positive charges per second flowing from left to right

- is equivalent to -

one coulomb of negative charges per second flowing from right to left.

Voltage: Formal Definition

- When we move a charge in the presence of other charges, energy is transferred. Voltage is the change in potential energy as we move between two points; it is a *potential difference*.

Energy, typically in Joules [J]

Voltage, typically in Volts [V]

$$v = \frac{dw}{dq}$$

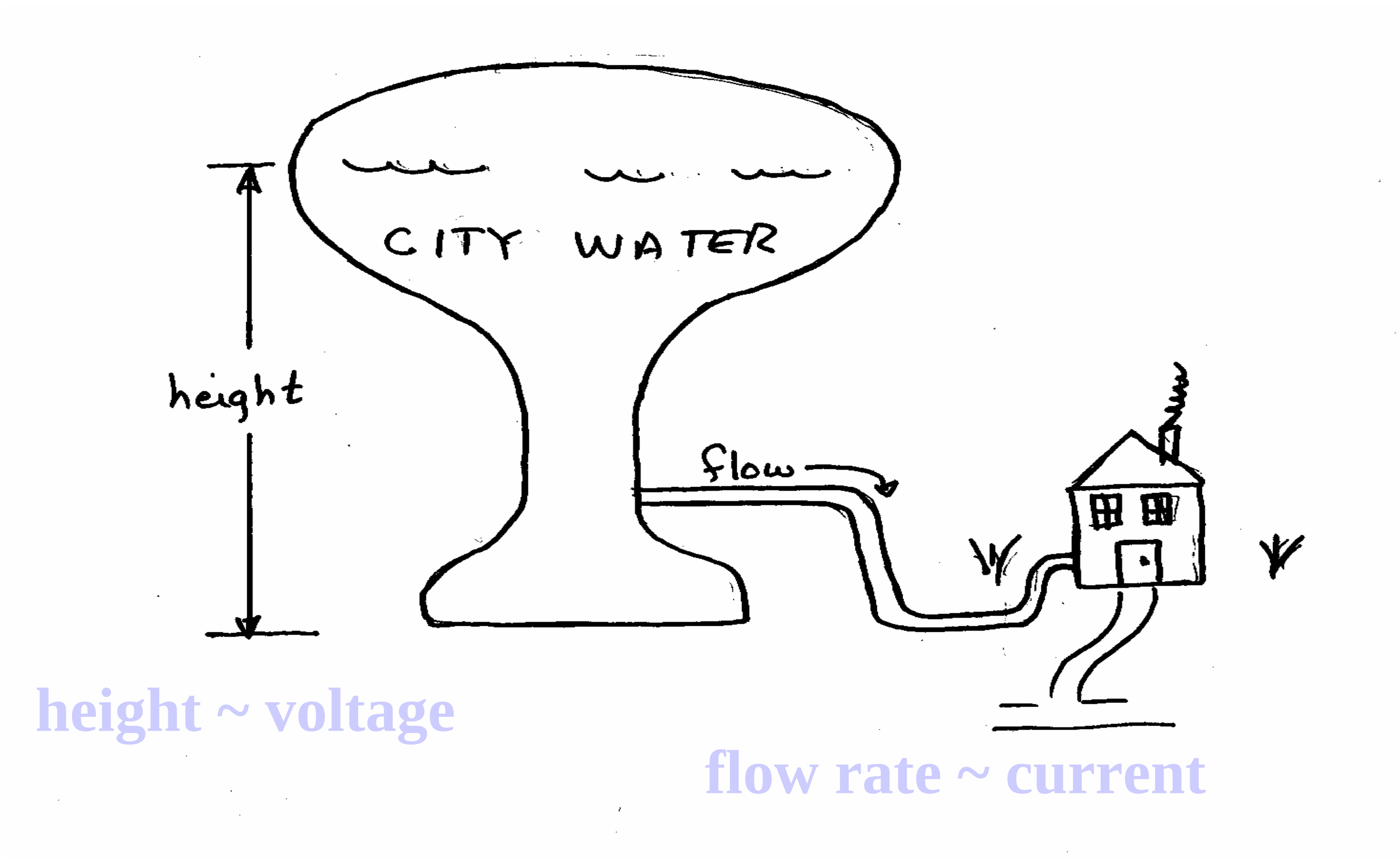
Charge, typically in Coulombs [C]

Volt

- The unit of voltage is the Volt. A Volt is defined as a Joule per Coulomb.
- Voltage is defined in terms of the energy gained or lost by the movement of <u>positive</u> charges.

One Joule of energy is lost from an electric system when a Coulomb of positive charges moves from one potential to another potential that is one Volt lower.

Hydraulic Analogy:Voltage and Current

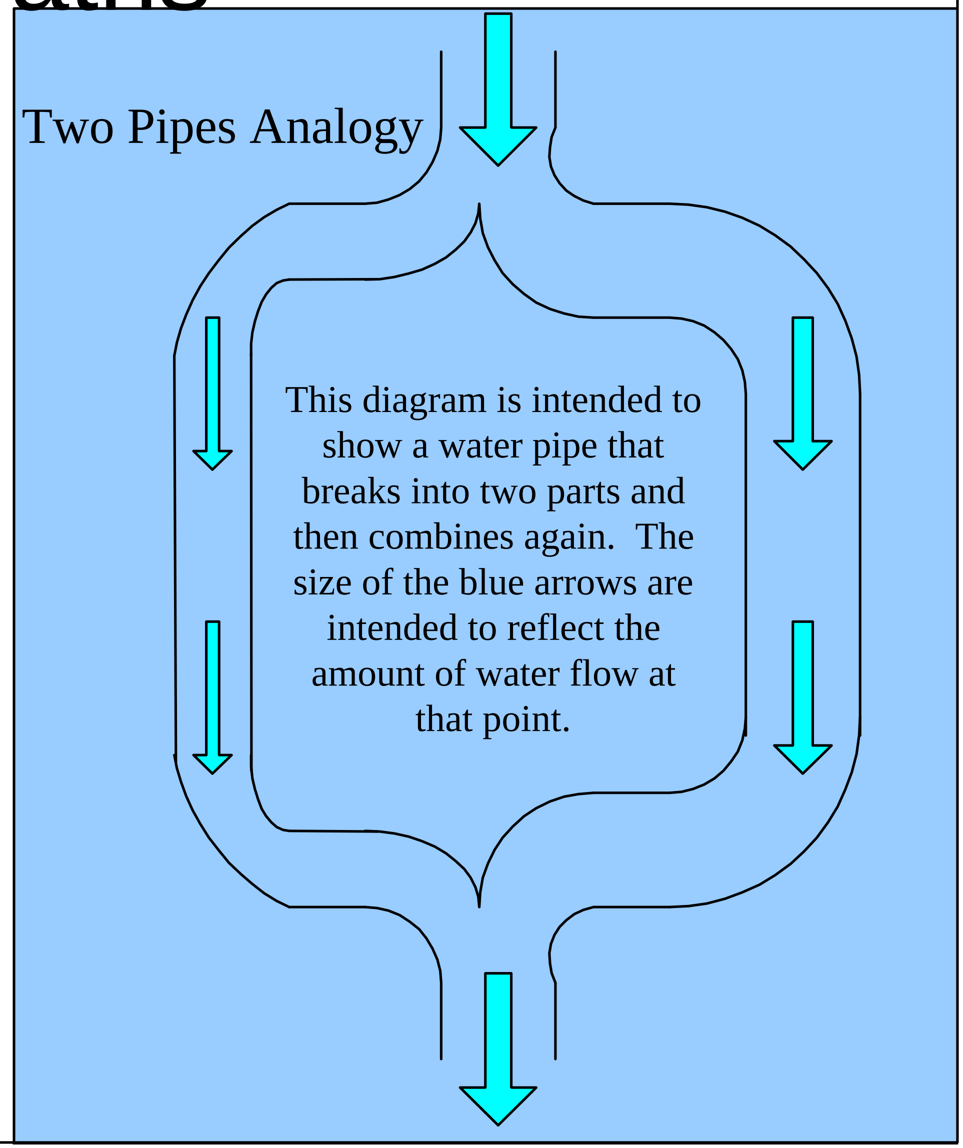


Hydraulic Analogy With Two Paths

Water is flowing *through* the pipes.

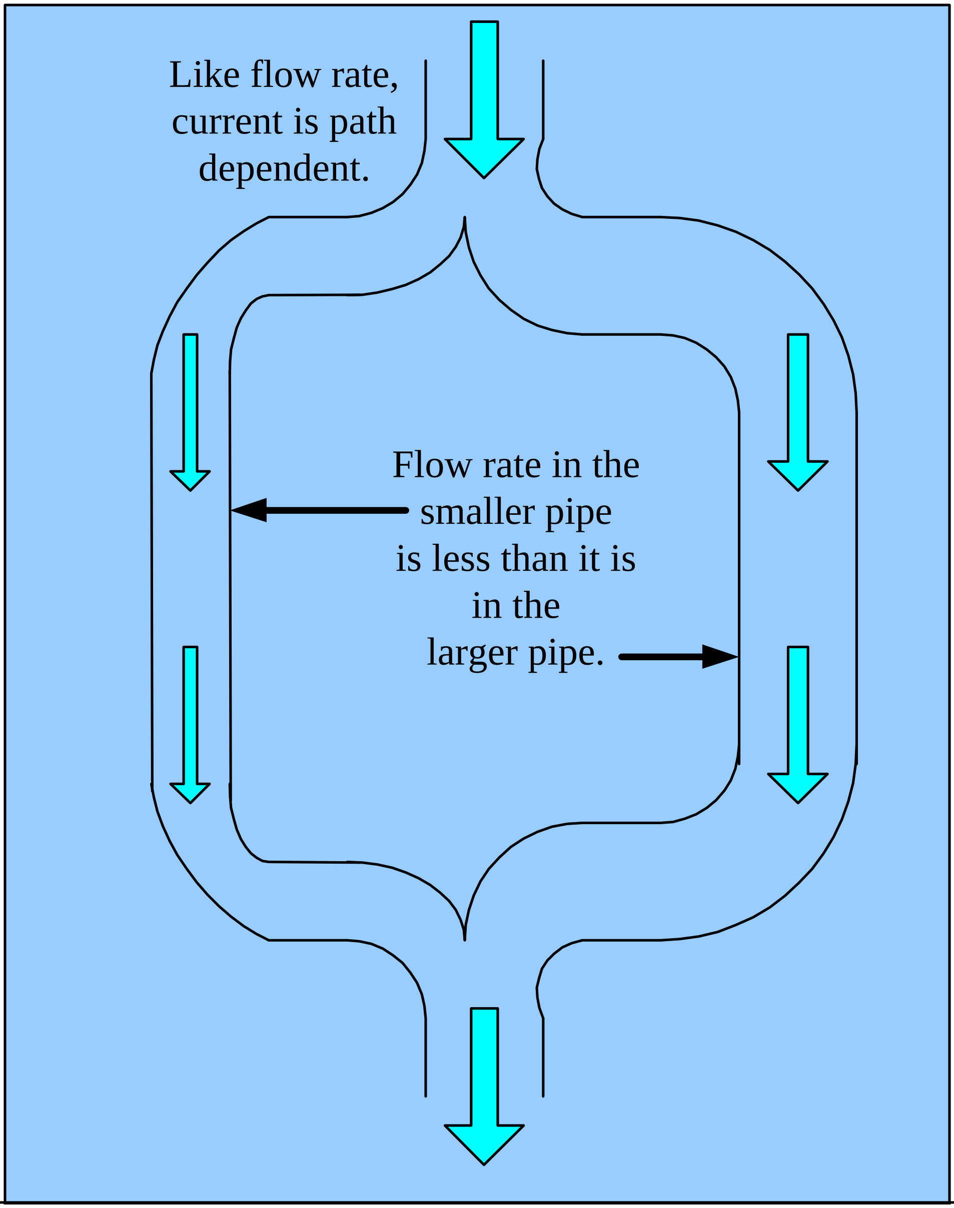
There is a height difference *across* these pipes.

We can extend this analogy to current *through* and voltage *across* an electric device…



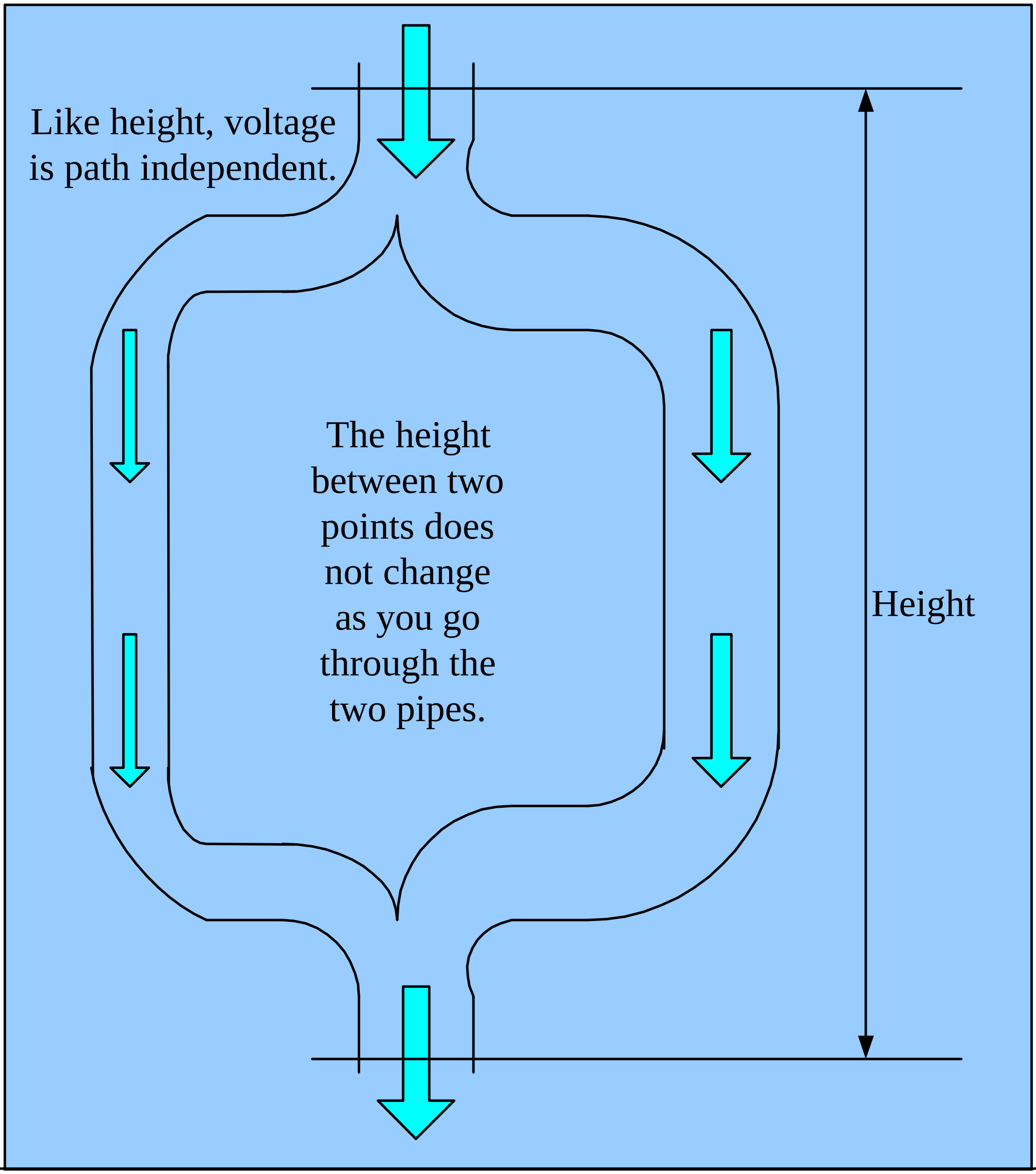
Current *Through*…

If we have two pipes connecting two points, the flow rate through one pipe can be different from the flow rate through the other. The flow rate depends on the path.



...Voltage *Across*

No matter which path you follow, the height is the same across those two points. The height does not depend on the path



Polarities

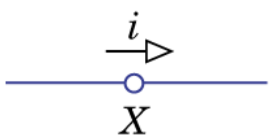
- Polarity: the sign, of the voltages and currents we use.
- Which way is the current flowing? Where is the potential higher?
- Two concepts are used:
  - Reference polarities
  - Actual polarities

Reference and Actual Polarities

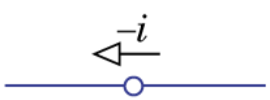
- The *reference polarity* is a direction chosen for the purposes of keeping track.
- Reference polarity must be assigned.
- The *actual polarity* is the direction something is actually going.
  - If the actual polarity is the same direction as the reference polarity, we use a positive sign for the value of that quantity.
  - If the actual polarity is the opposite direction from the reference polarity, we use a negative sign for the value of that quantity.

Polarities for Currents

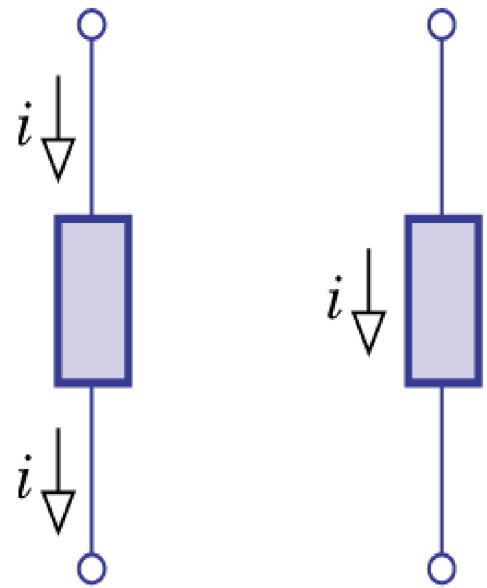
- For current, the reference polarity is given by an arrow.
- The actual polarity is indicated by a value that is associated with that arrow.



(a) Current reference arrow for equivalent positive charge transfer from left to right

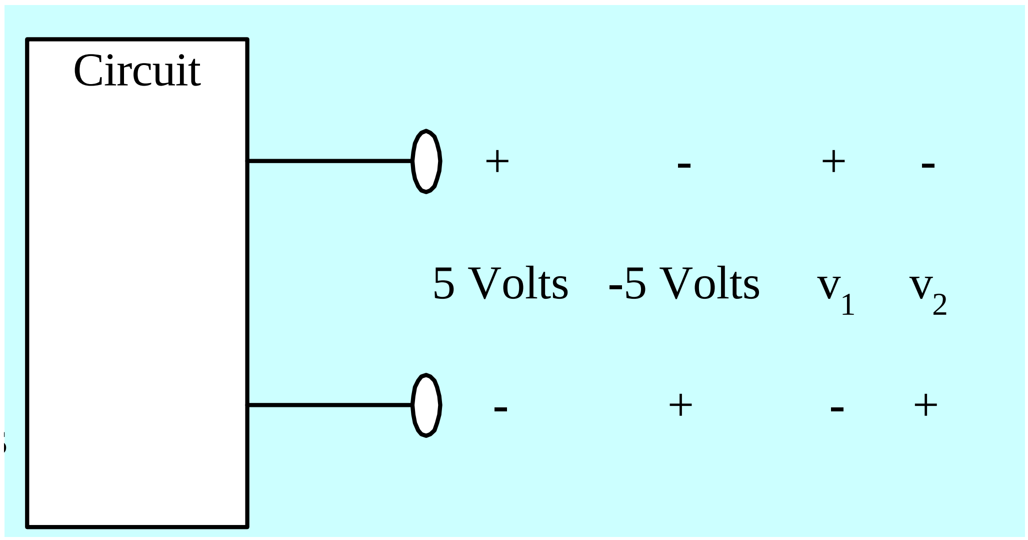


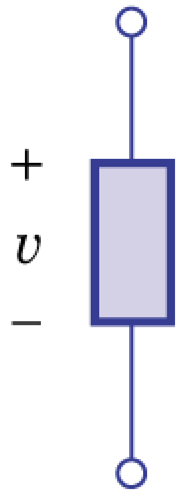
(b) Actual current direction when i is negative



Polarities for Voltages

- The reference polarity for voltage is given by a + symbol and a – symbol.
- The actual polarity is indicated by a value that is placed between the + and - symbols.
- The voltages v_1 and v_2 are not defined until the + and – symbols are shown.





Energy and Power
Source and Load (Polarity)

Overview

- Definitions of Energy and Power
- Sign Conventions for power direction
- Which way do the energy and power go (Active or Passive)?
- Hydraulic analogy

Joule Definition

- The unit for energy is the Joule [J].
- A Joule is a Newton-meter.
- In everything that we do in this class, energy will be conserved.
- Supply vs. Absorb: Active vs. Passive.

Power

- Power is the rate of change of the energy. It is the rate at which the energy is absorbed or delivered.
- Supply vs. Absorb: Active vs. Passive.

$$p = \frac{dw}{dt}$$

Power, typically in Watts [W]

Energy, typically in Joules [J]

Time, typically in seconds [s]

Power from Voltage and Current

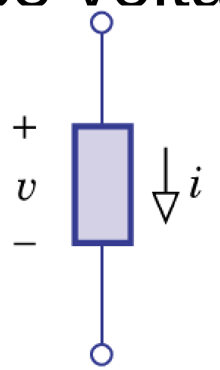
Power can be found from the voltage and current, as shown below. Note that if voltage is given in [V], and current in [A], power will come out in [W].

$$p = \frac{dw}{dt} = \frac{dw}{dq} \times \frac{dq}{dt} = vi$$

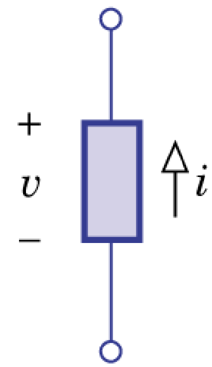
Sign Convention – Definition

- The <u>passive sign convention</u> is when the reference polarity for the current is in the direction of the reference voltage d

- The <u>active sign convention</u> is when the reference polarity for the current is in the direction of the reference voltage rise.



(a) Passive polarity convention



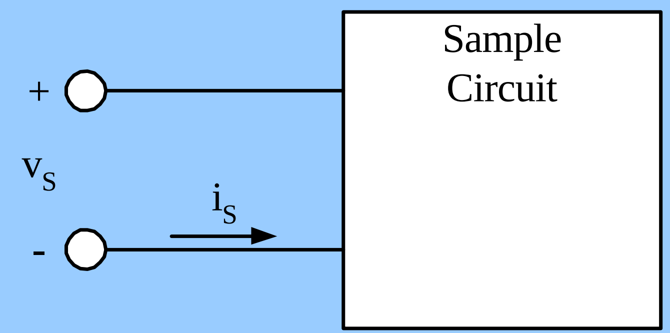
(b) Active polarity convention

Using Sign Conventions for Power Direction – The Rules

- When we use the passive sign convention to assign reference polarities, *vi* gives the power absorbed, and –*vi* gives the power delivered.
- When we use the active sign convention to assign reference polarities, *vi* gives the power delivered, and –*vi* gives the power absorbed.

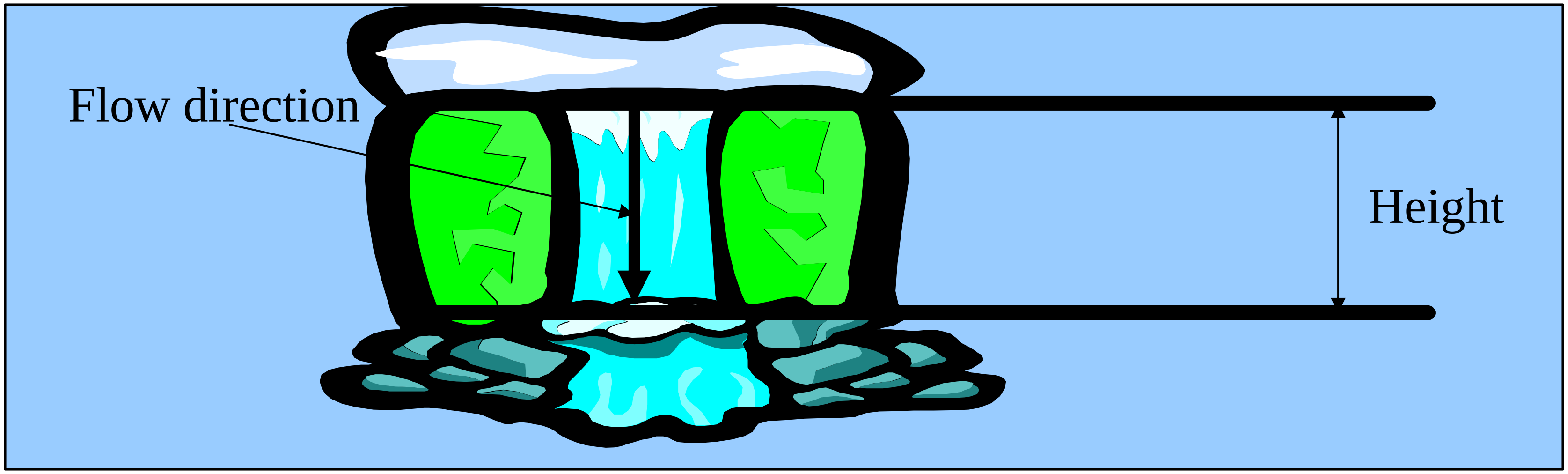
Example of Determining the Power with Polarity

	Passive Convention	Active Convention
Power absorbed	$p_{abs} = vi$	$p_{abs} = -vi$
Power delivered	$p_{del} = -vi$	$p_{del} = vi$



Hydraulic Analogy for Power Directions

- Imagine a waterfall.

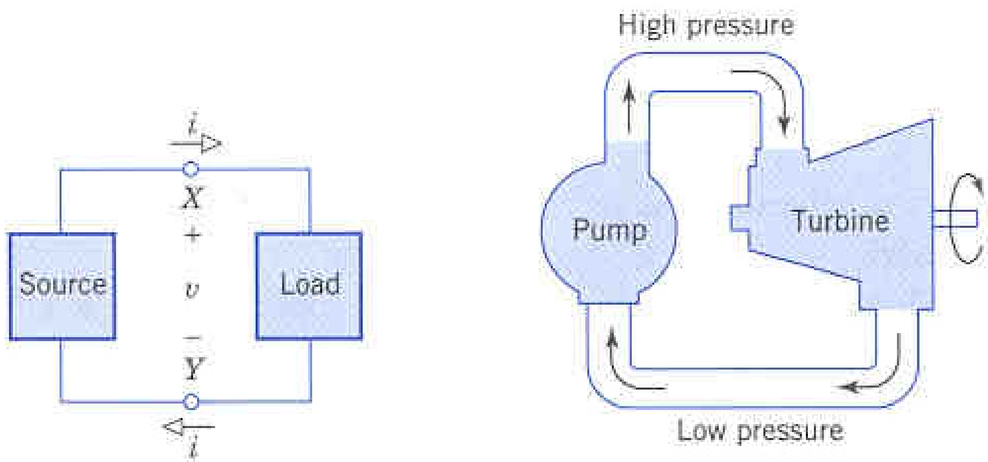


The waterflow is in the direction of the drop in height. Thus, this is analogous to the passive sign convention.

$$p_{abs} = vi$$

Another Hydraulic Analogy

- As Carlson puts it, “The pump (*source*) forces water flow (*current*) through pipes (*wires*) to drive the turbine (*load*). The water pressure (*potential*) is higher at the inlet port of the turbine than at the outlet.”



(*a*) Source-load circuit (*b*) Analogous hydraulic system

Figure 1.9

Note that the Source is given with reference polarities in the active convention, and the Load with reference polarities in the passive convention. As a result, in this case, since all quantities are positive, the Source delivers power, and the Load absorbs power.

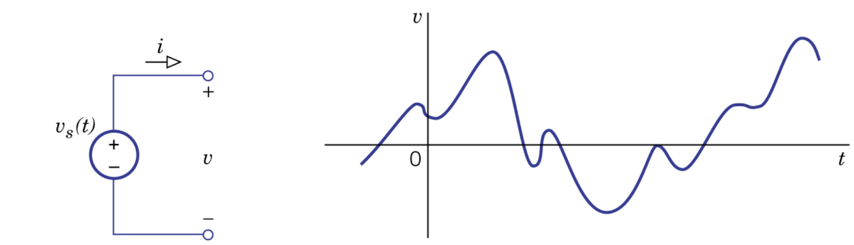
Some Resistive Circuit Elements

Overview

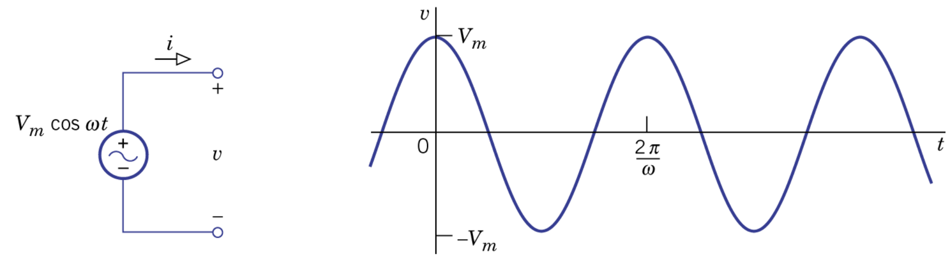
- Independent voltage source and current source
- Resistors and Ohm's Law
- How to describe "behavior" of a circuit:
  - $v(t)$, $i(t)$
  - *i-v curve* (*v-i curve*)

Voltage Sources

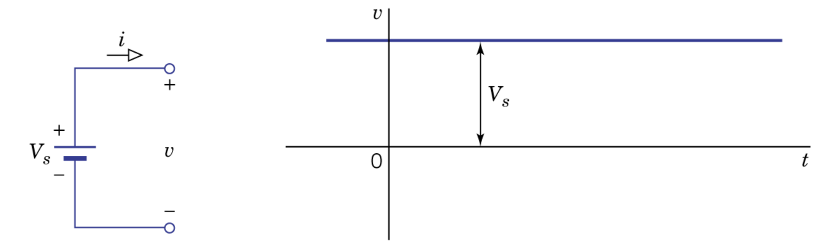
- A voltage source is a two-terminal circuit element that maintains a voltage across its terminals.
- The voltage value is the defining characteristic.
- Any value of the current can go through the voltage source (including zero).



(a) Ideal voltage source



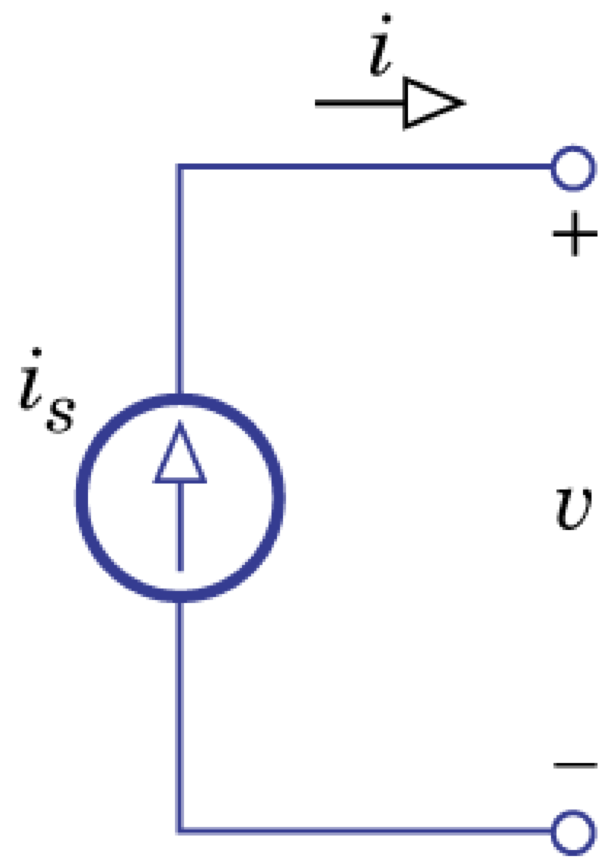
(b) AC voltage source



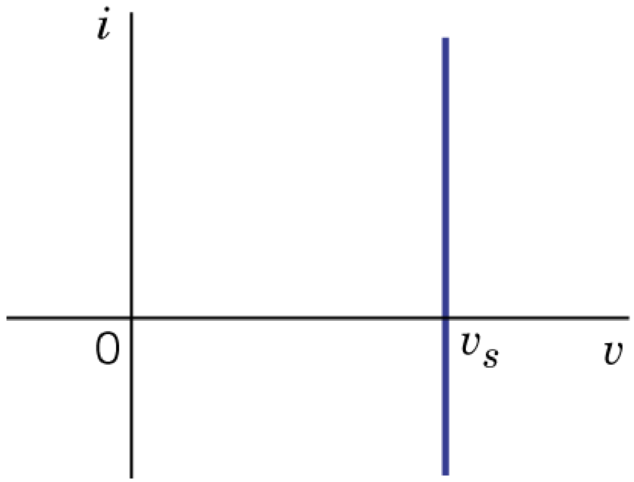
(c) Battery

Current Sources

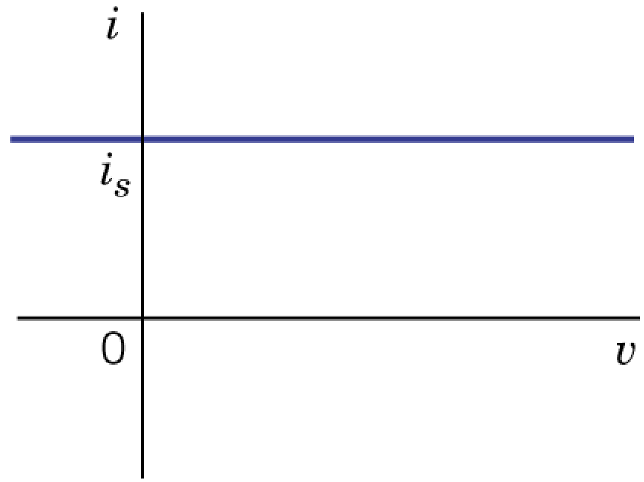
- A current source is a two-terminal circuit element that maintains a current through its terminals.
- The current value is the defining characteristic.
- Any voltage can be across the current source (including zero).



Ideal Sources



(a) Voltage source

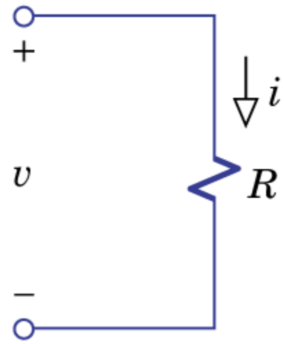


(b) Current source

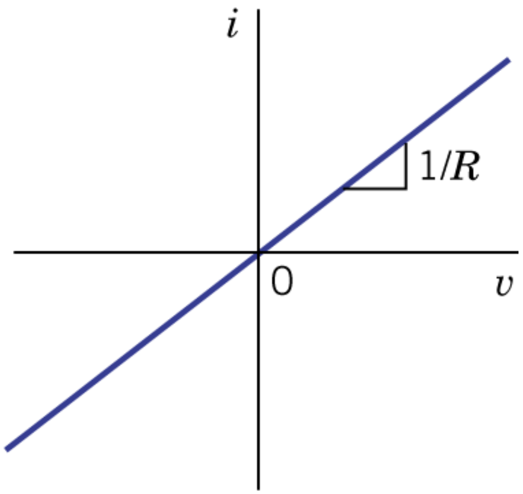
i-v curve (*v-i curve*)

Ohm's Law and Resistors

- A (linear) resistor is a two terminal circuit element that has a constant ratio of the voltage across its terminals to the current through its terminals.
- Passive sign convention.



(a) Symbol



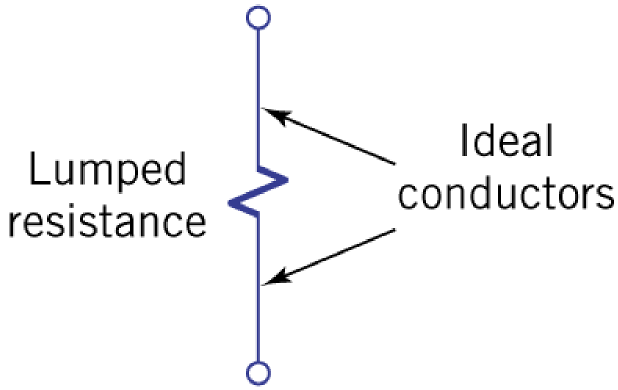
(b) i–v curve

Ohm's law: $$R = \frac{v_R}{i_R}$$

Lumped Circuits

- Lumped-parameter models: spatially distributed property is lumped entirely at one point.
- EM wavelength is much larger than dimensions of the circuit.
- Only lumped circuits are considered in this course.

(a) Resistance distributed between two terminals



(b) Lumped-parameter model

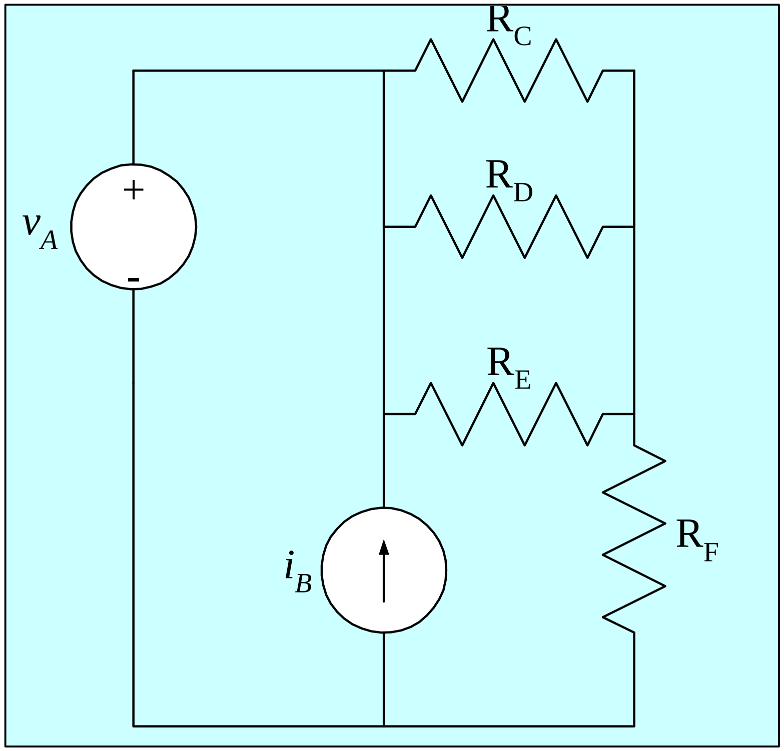
Lumped vs. Distributed

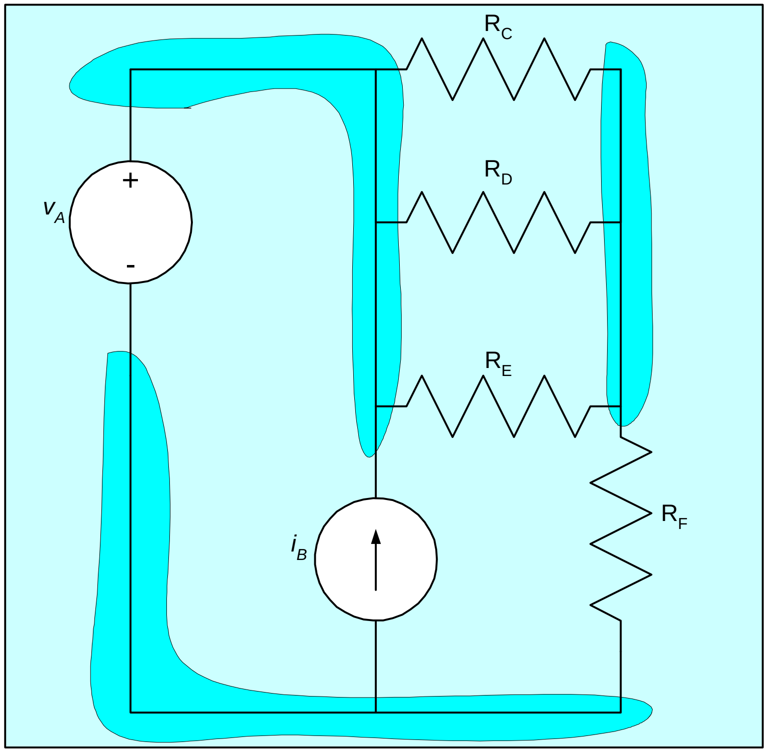
- Lumped circuit:
  - electromagnetic wavelength >> largest dimension of the circuit
  - the respective locations of circuit elements are not important
- Distributed circuits
  - when the lumped approximation is not valid
  - examples: transmission lines (will be covered in the EM class)

1.4 Kirchhoff’s Laws

Node

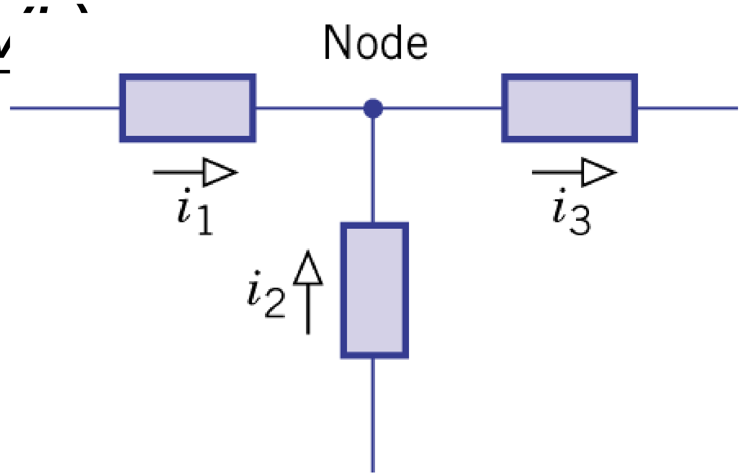
- Node: connection point of two or more circuit elements.





KCL (Node)

- Charge is conserved and does not accumulate at a node.
- Kirchhoff's current law (KCL): The sum of the currents leaving any node equals the sum of the currents entering that node.
- *Elements in series carry the same current. (Dual with KVL)*



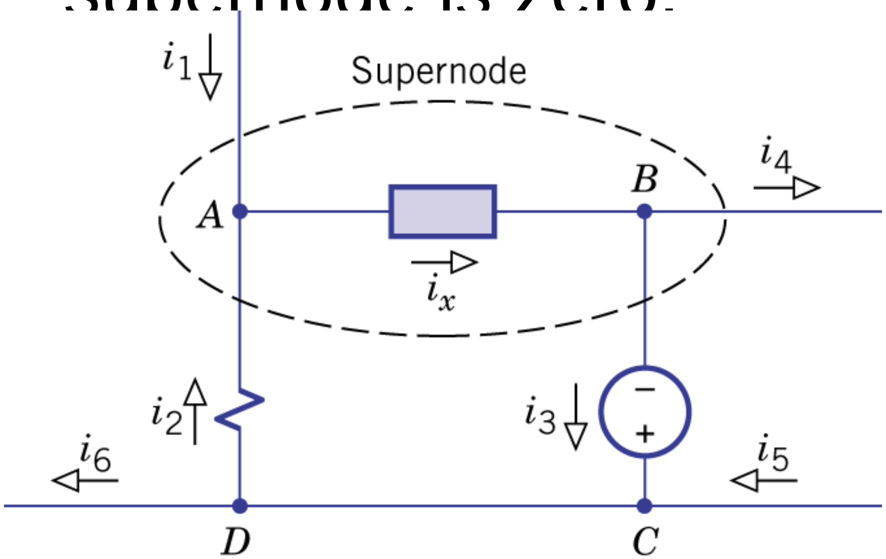
$$i_3 = i_1 + i_2$$

or

$$i_1 + i_2 - i_3 = 0$$

KCL (Supernode)

- Supernode: any closed region contains two or more nodes and the wires intersected by the boundary are only intersected once (*closed surface*).
- The algebraic sum of all currents into any supernode is zero.



Node A

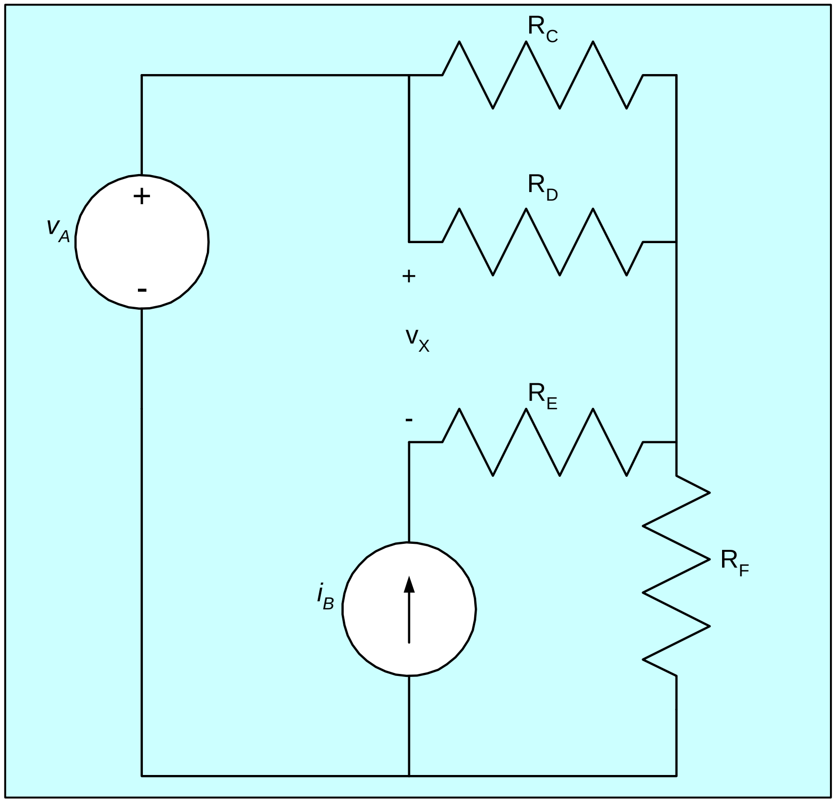
Supernode

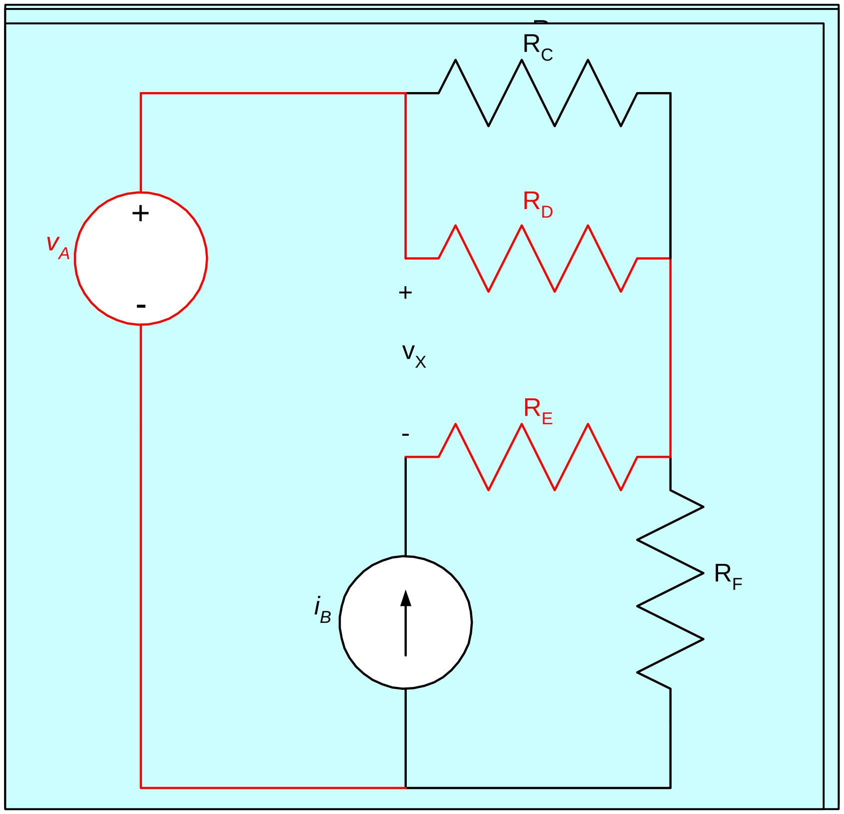
$$\left.\begin{aligned} i_1 + i_2 - i_x &= 0 \\ i_x - i_3 - i_4 &= 0 \end{aligned}\right\} \Rightarrow i_1 + i_2 - i_3 - i_4 = 0$$

Node B

Loop

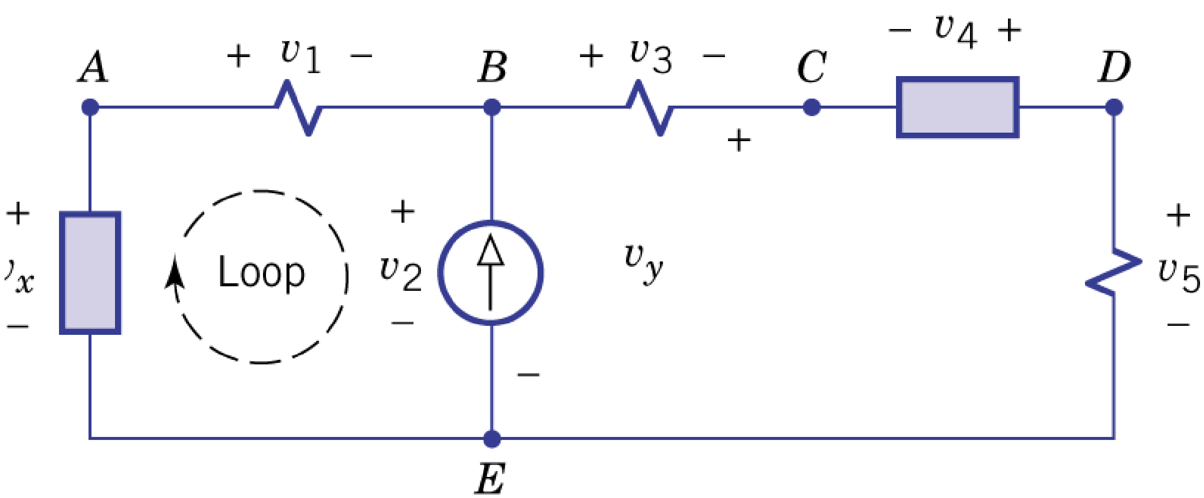
- A loop is any path that goes from node to node, returns to the staring node and passing only once through each node.

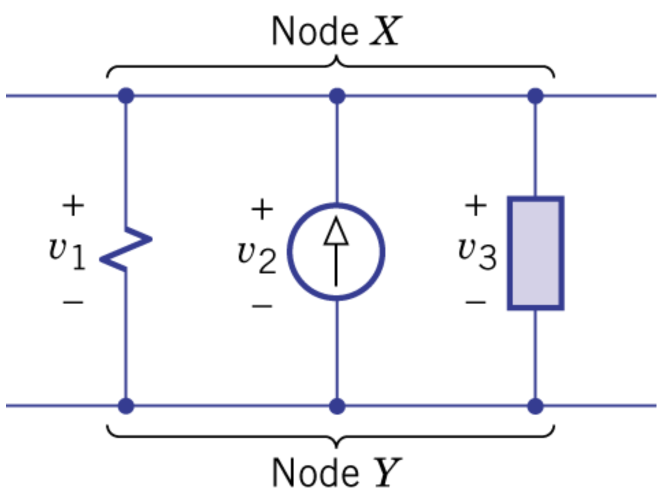




KVL (Loop)

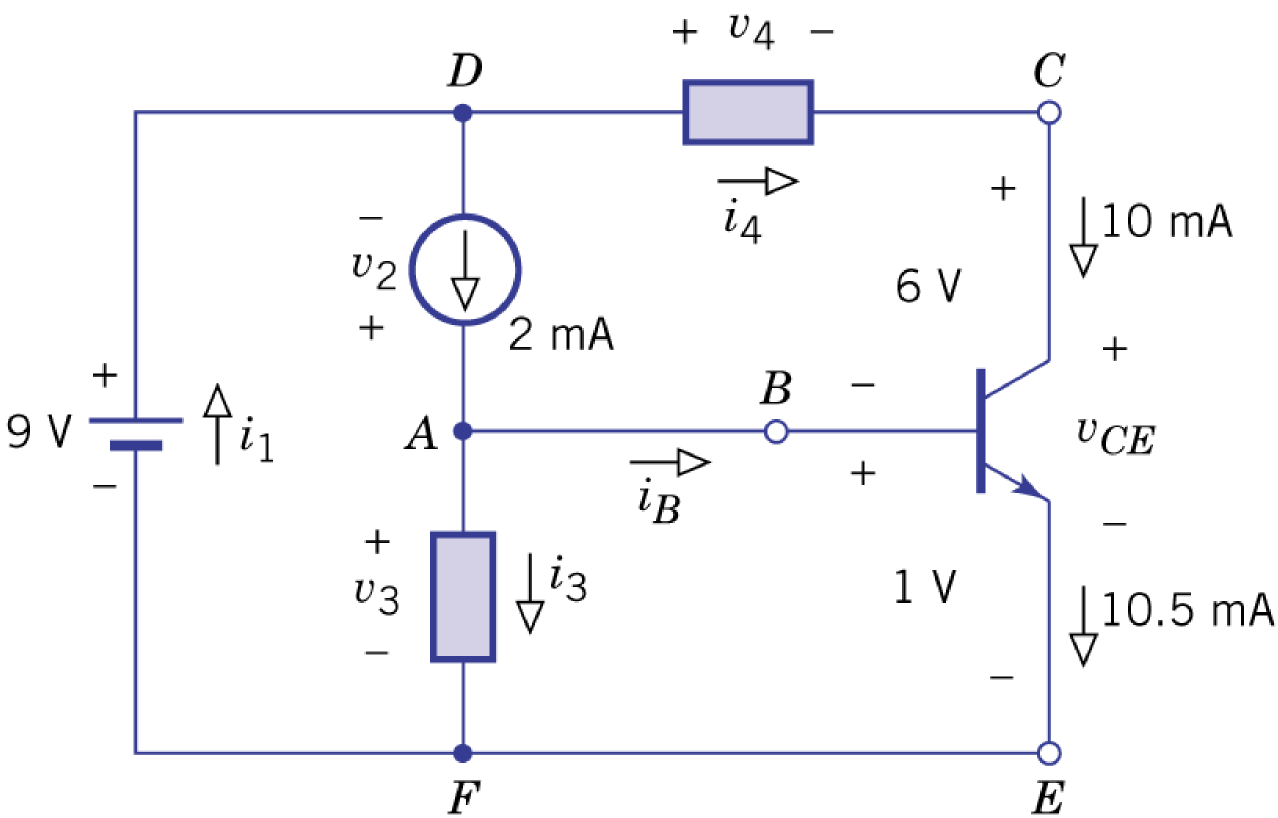
- Kirchoff's voltage law (KVL): the sum of voltage drop around a loop is the sum of voltage rise.
- The algebraic sum of all voltage drops around any loop equals zero.
- *Elements in parallel have the same voltage across each one of them. (Dual with KCL)*





Example 1.7

- Determine the remaining unknown circuit variables.



$i_1 = 12mA$

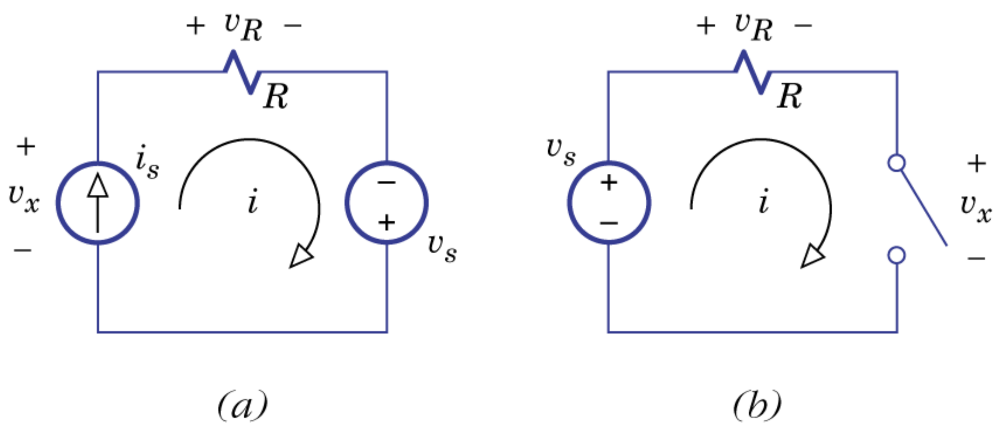
$i_3 = 1.5mA$

$v_4 = 2V$

$v_2 = -8V$

Elementary Circuit Analysis

- Series
  - KCL: same loop current.
  - KVL is used for circuit analysis.



$$v_x = v_R - v_s = Ri_s - v_s$$

$$i = 0$$

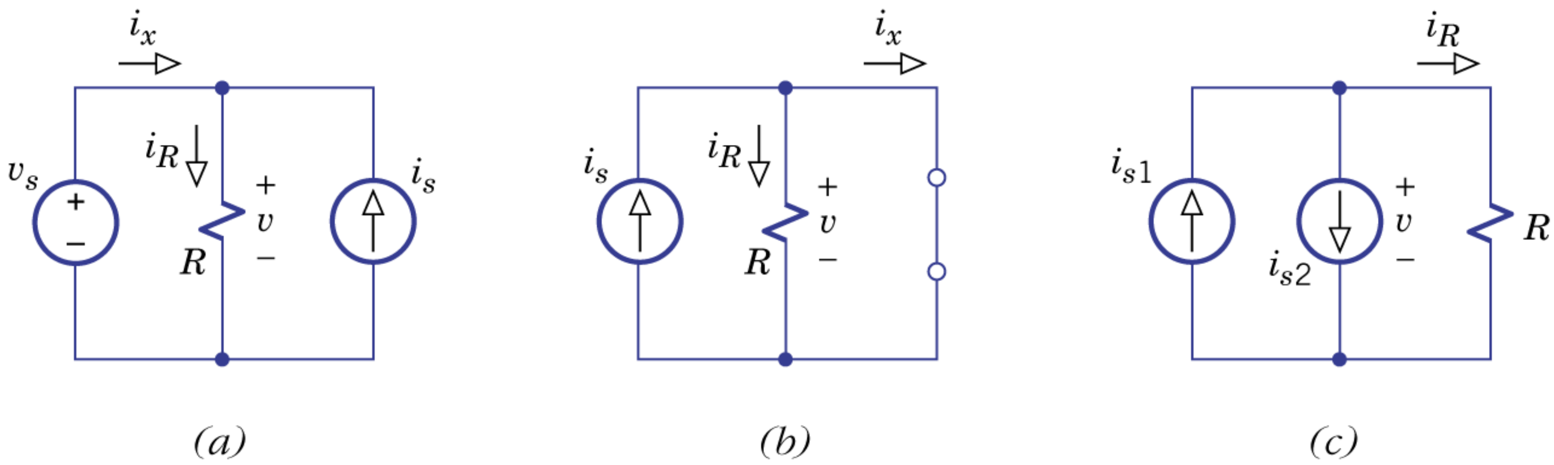
$$v_R = 0, v_x = v_s$$

$$v_R = v_{s1} - v_{s2}$$

$$i = \frac{v_R}{R} = \frac{(v_{s1} - v_{s2})}{R}$$

Elementary Circuit Analysis

- Parallel
  - KVL: same node voltage
  - KCL is used for circuit analysis

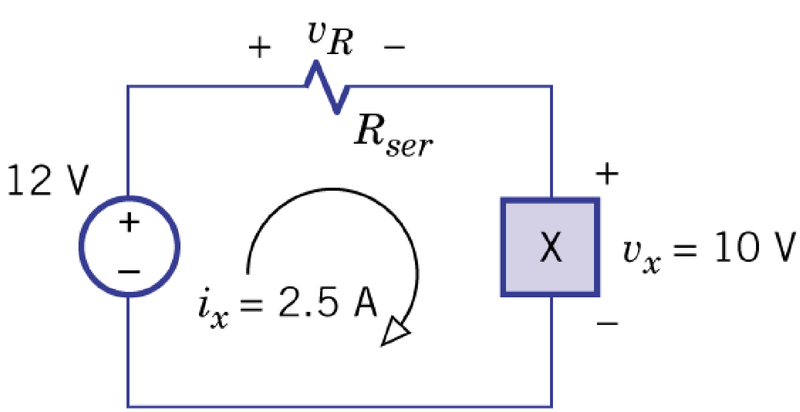


$$i_x = i_R - i_s$$
$$= Gv_s - i_s$$

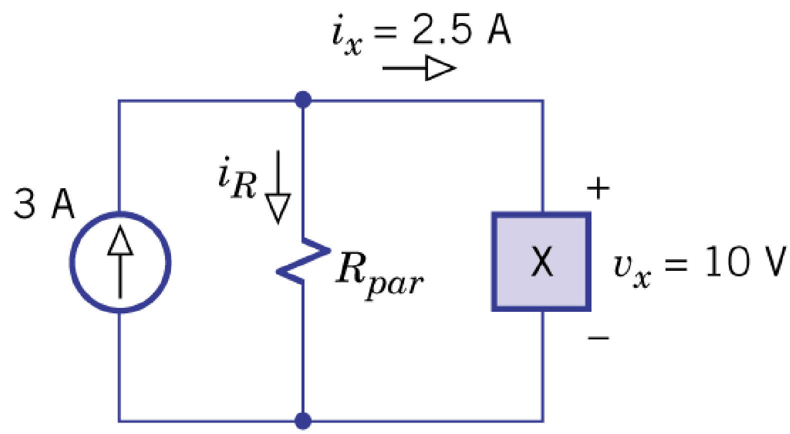
$$i_R = 0$$
$$i_x = i_s$$

$$i_R = i_{s1} - i_{s2}$$
$$v = i_R R = (i_{s1} - i_{s2})R$$

Example 1.8



(a) Electronic device with series voltage source and resistor



(b) Electronic device with parallel current source and resistor

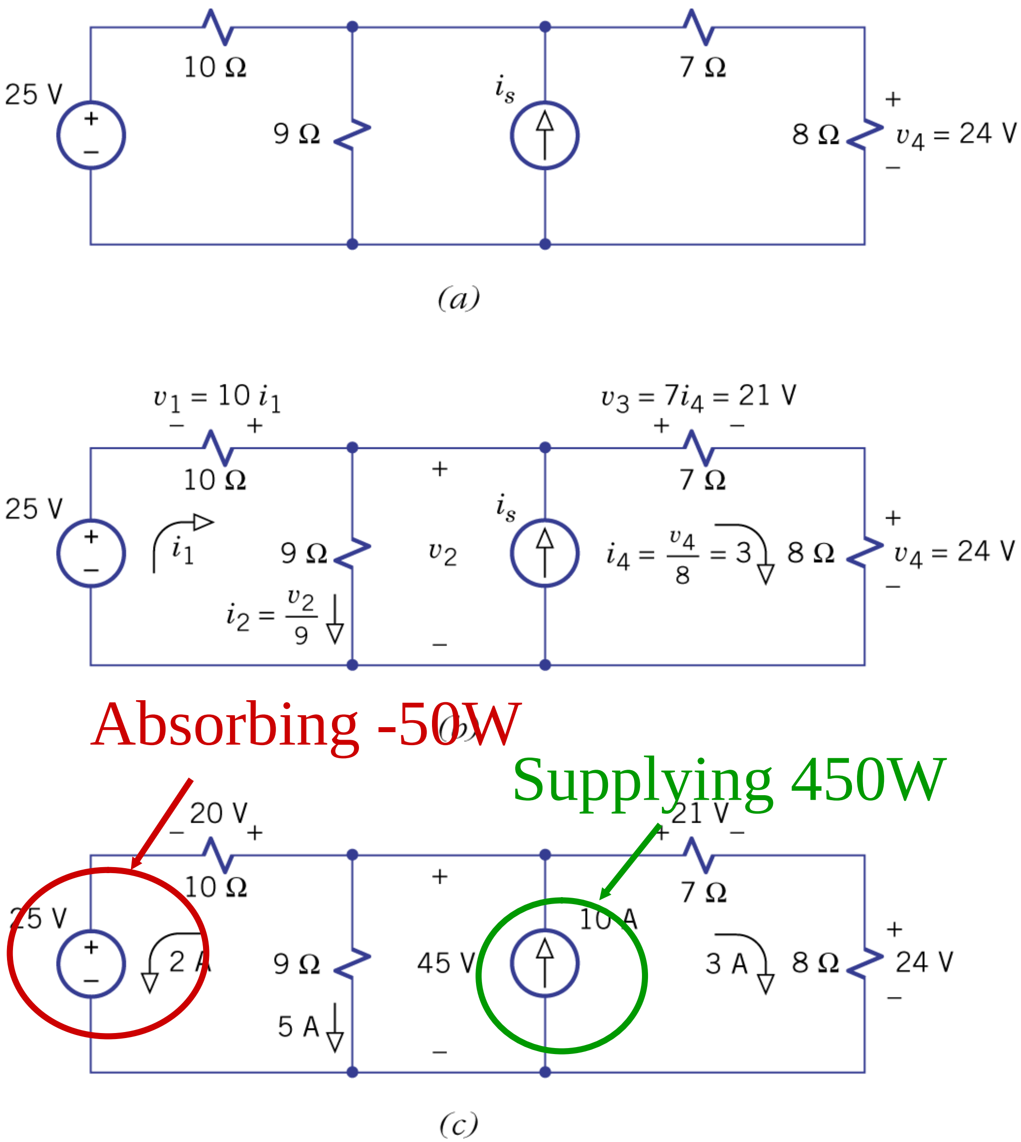
- Operate at v_x=10V, i_x=2.5A
- Supplied by 12V or 3A
- A resistor is required
- Find R_{ser} and R_{par}.

- R_{ser}=(12-10)/2.5=0.8
- R_{par}=10/0.5=20

Branch Variable Analysis

- Branch variable analysis: assign voltage or current associated with individual elements as immediate variables.

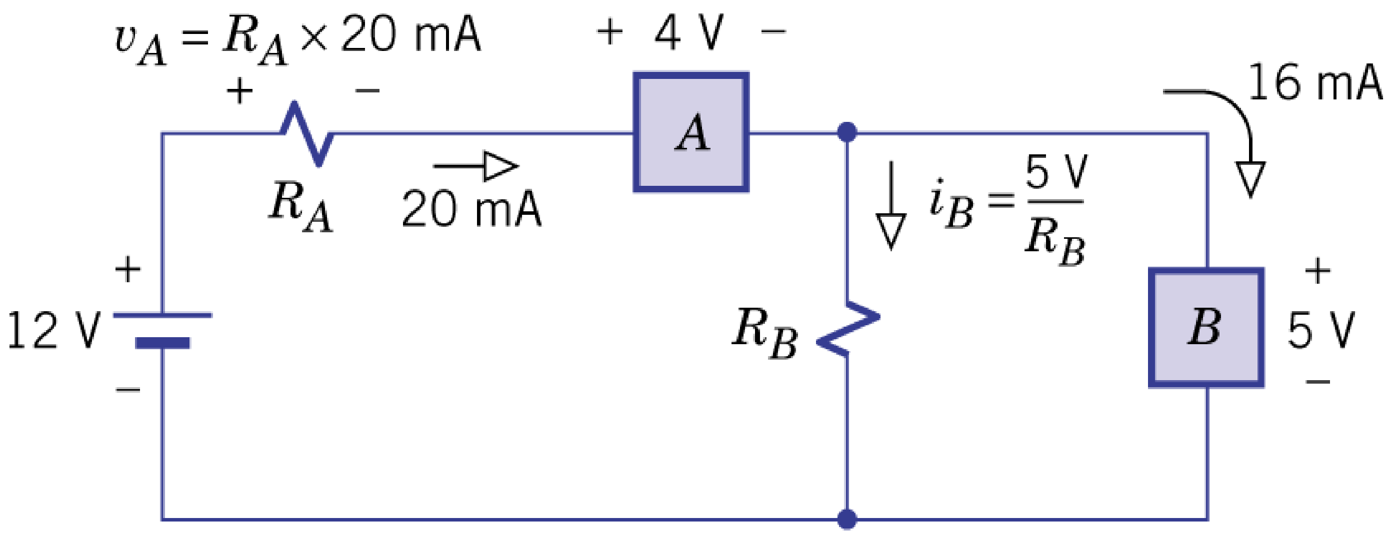
Example 1.9



- Find i_s and the power supplied by the sources.
- i_s =3+5+2=10A
- Total supplied power = p_v+p_i=-50+450 =400W

Example 1.10

- Device A → (4V, 20mA)
- Device B → (5V, 16mA)
- Powered by a 12-V battery
- R_A=3V/20mA=150Ω
- R_B=5V/4mA=1.25kΩ



- More than one configuration.

Chapter 1: Problem Set

- 34, 37, 40, 47