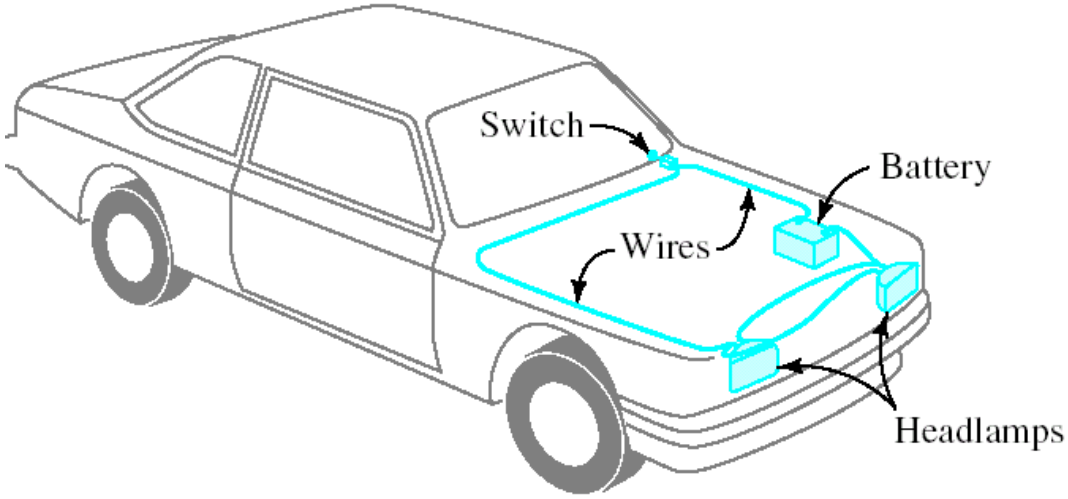
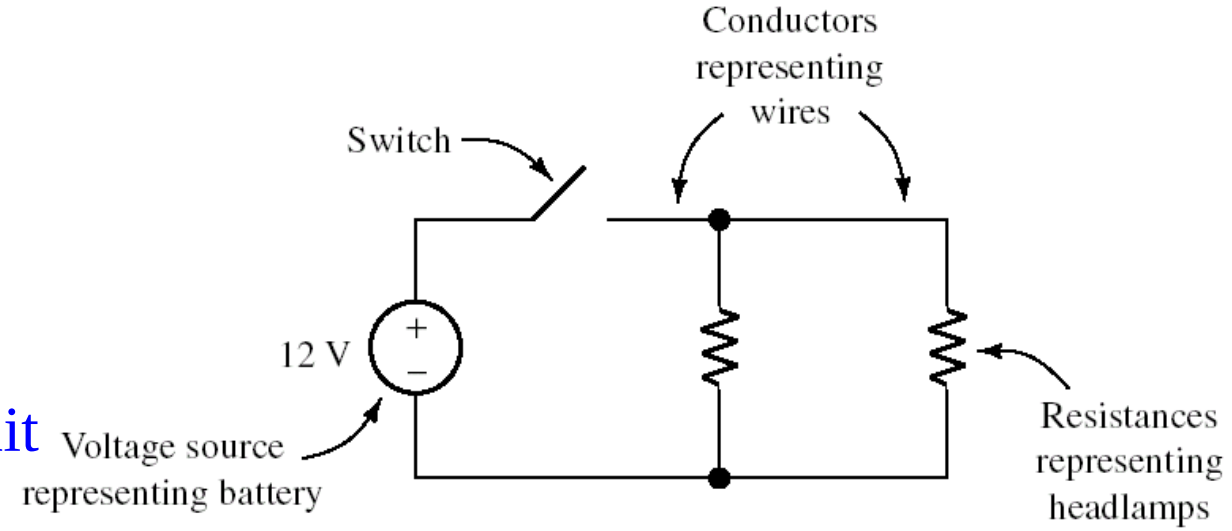
Chapter 1 Introduction

1.2 Circuits, Currents, and Voltages

Figure 1.2 The headlight circuit. (a) The actual physical layout of the circuit. (b) The circuit diagram.



(a) Physical configuration



(b) Circuit diagram

The circuit consists of

- A battery
- A switch
- The headlamps
- Wires

Switch is closed

- Current flows through the circuit

Switch is open

- The current does not flow

Electrical Circuits (電路)

An electrical circuit consists of various type of circuit elements (電路元件) connected in closed path by conductors (導體).

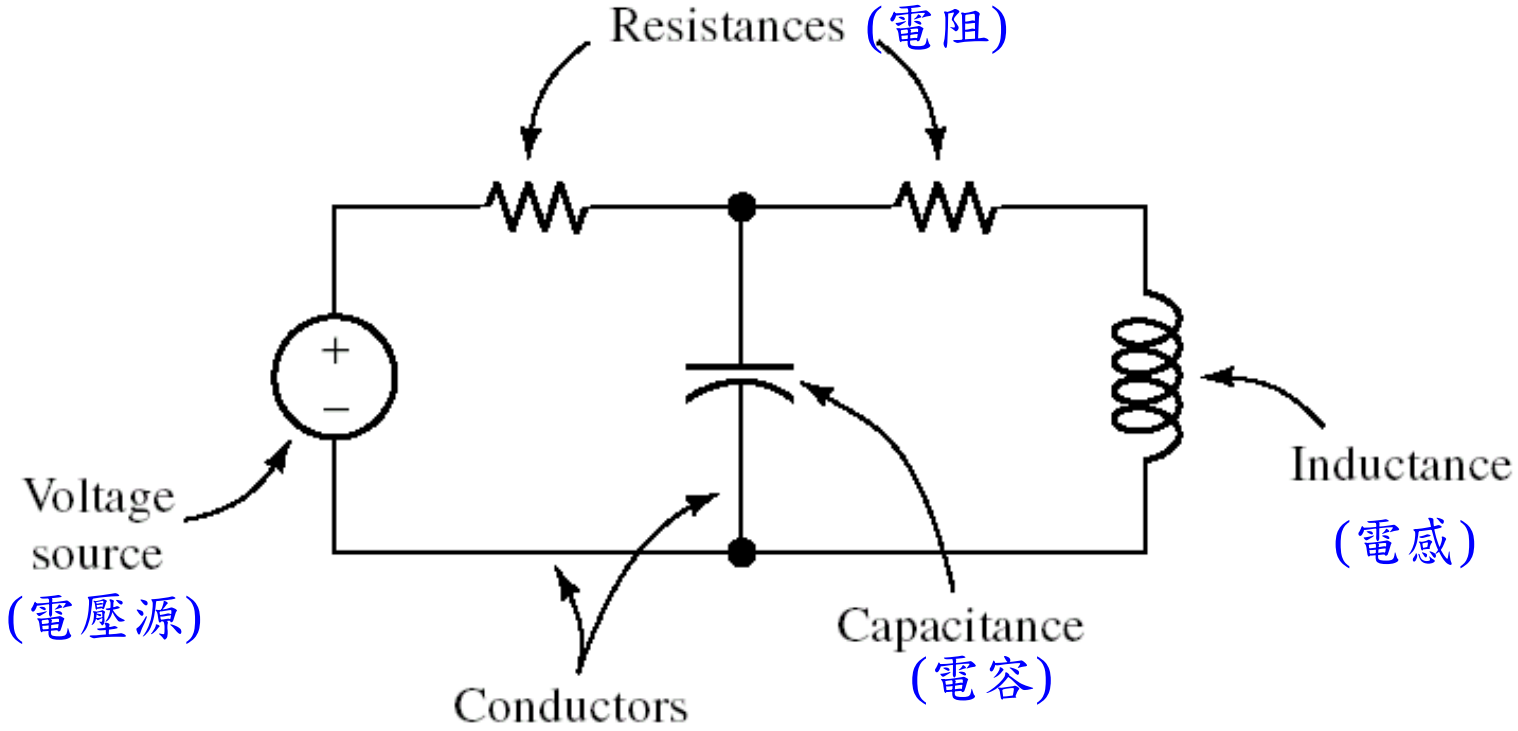


Figure 1.3 An electrical circuit consists of circuit elements, such as voltage sources, resistances, inductances, and capacitances, connected in closed paths by conductors.

Circuit Elements

金膜電阻

電容

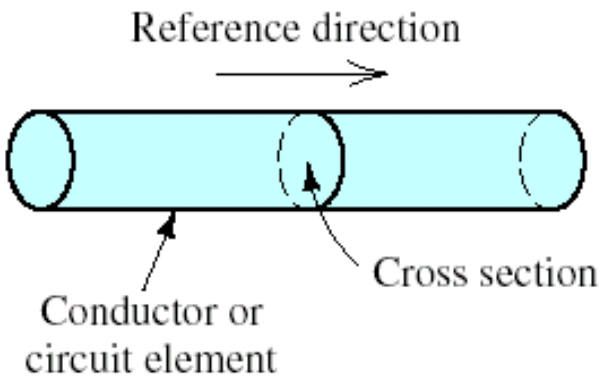
電感

Electrical Current (電流)

Electrical current is the time rate of flow of electrical charge (單位時間通過電荷量) through a conductor or circuit element. The units are amperes (A), which are equivalent to coulombs (庫倫) per second (C/s).

Note:
The charge on an electron is -1.602×10^{-19} C

Electrical Current



$$i(t) = \frac{dq(t)}{dt}$$

$$q(t) = \int_{t_0}^{t} i(t)dt + q(t_0)$$

- $q(t)$: 在時間 t 的淨電荷 (net charge)
- Positive charge crossing in the reference direction (參考方向) is counted as a positive contribution to net charge

Example 1.1 Determine Current Given charge

Given

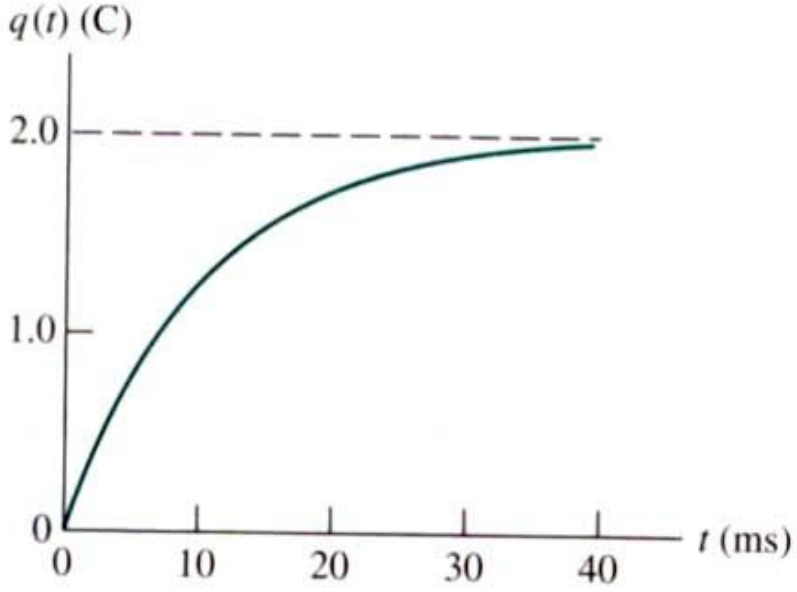
$$q(t) = \begin{cases} 0, & \text{for } t < 0 \\ 2 - 2e^{-100t} & \text{for } t > 0 \end{cases}$$

Sketch $q(t)$ & $i(t)$ to scale vs. time.

Sol:

$$i(t) = \frac{dq(t)}{dt} = \begin{cases} 0, & \text{for } t < 0 \\ \dfrac{d(2-2e^{-100t})}{dt} & \text{for } t > 0 \end{cases}$$

$$= \begin{cases} 0, & \text{for } t < 0 \\ 200e^{-100t} & \text{for } t > 0 \end{cases}$$



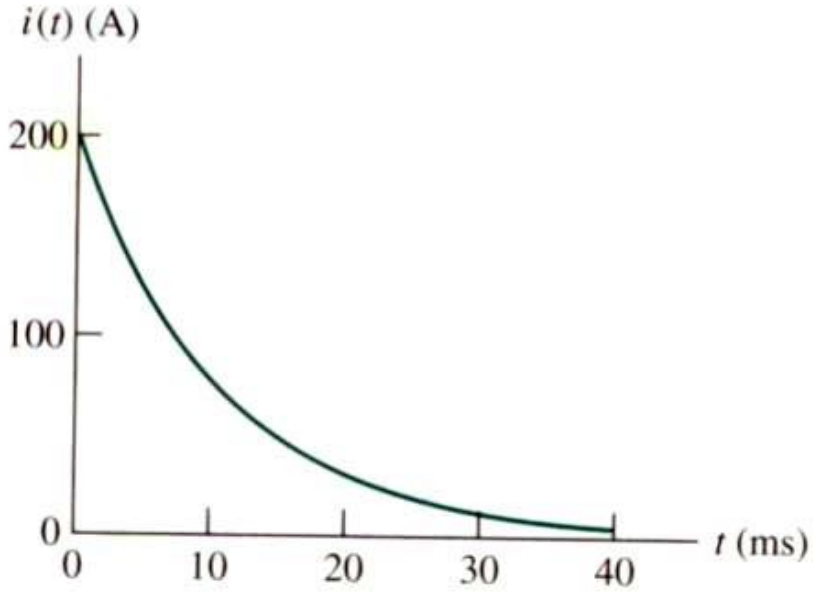


Figure 1.5 Plots of charge and current versus time for Example 1.1. *Note*: The time scale is in milliseconds (ms). One millisecond is equivalent to 10^{-3} seconds.

Reference Directions (參考方向)

In analyzing electrical circuits, we may not initially know the actual direction of current flow.

Therefore, we start by assigning current variables and arbitrarily selecting a reference direction.

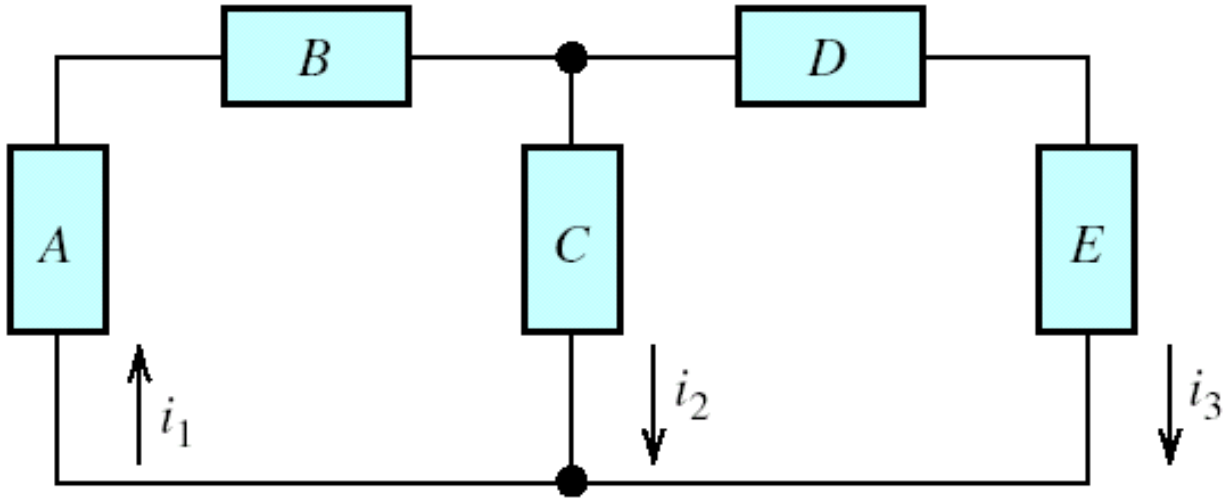
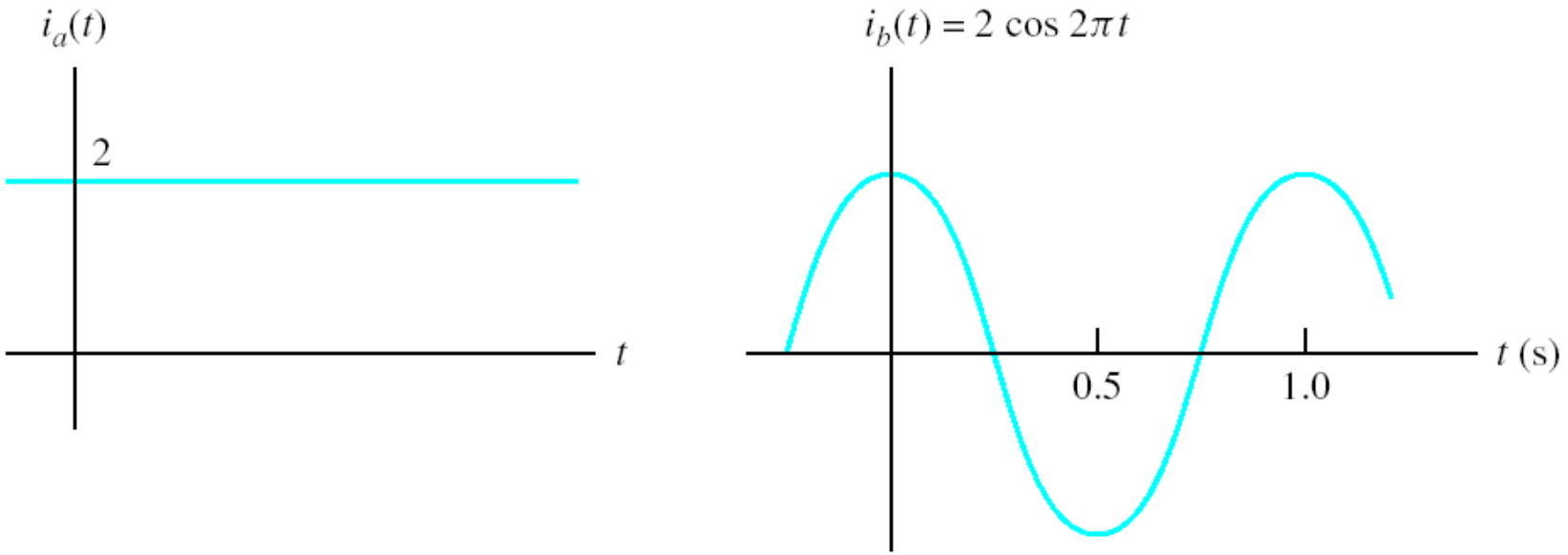


Figure 1.6 In analyzing circuits, we frequently start by assigning current variables i_1, i_2, i_3, and so forth.

Direct Current (DC, 直流電)
Alternating Current (AC, 交流電)

When a current is constant with time, we say that we have **direct current**, abbreviated as dc. On the other hand, a current that varies with time, reversing direction periodically, is called **alternating current**, abbreviated as ac.

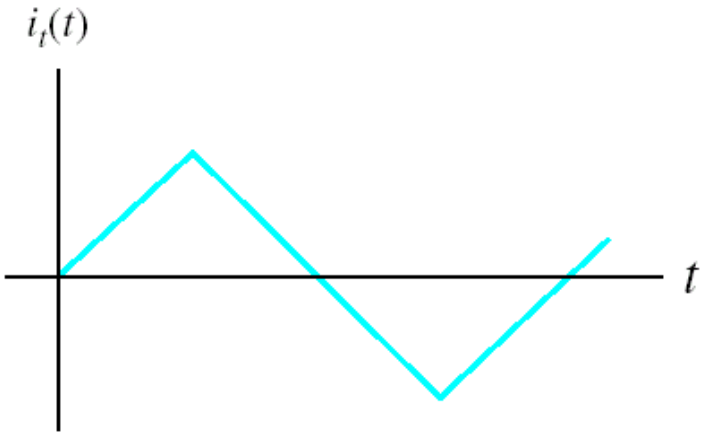
Figure 1.7 Examples of dc and ac currents versus time.



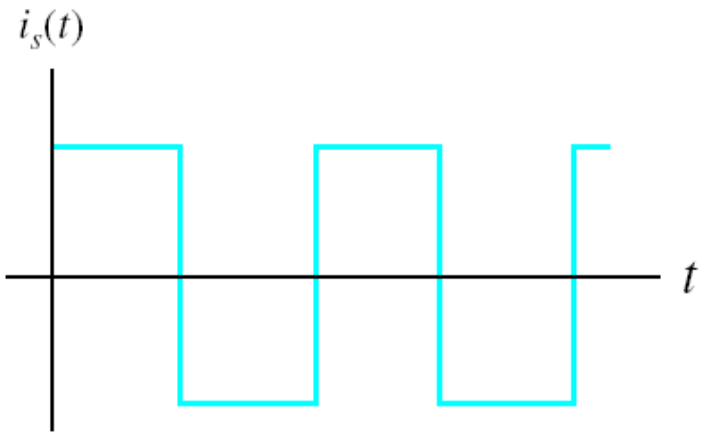
(a) Dc current

(b) Ac current

Figure 1.8 Ac currents can have various waveforms.



(a) Triangular waveform

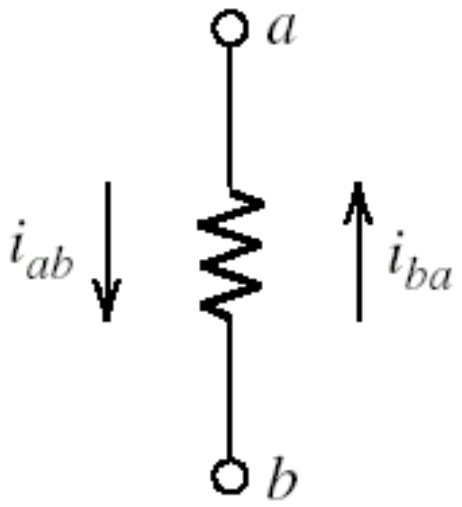


(b) Square waveform

Double-Subscript Notation

We can use double subscripts to define the reference direction for the current.

Figure 1.9 Reference directions can be indicated by labeling the ends of circuit elements and using double subscripts on current variables. The reference direction for i_{ab} points from a to b. On the other hand, the reference direction for i_{ba} points from b to a.



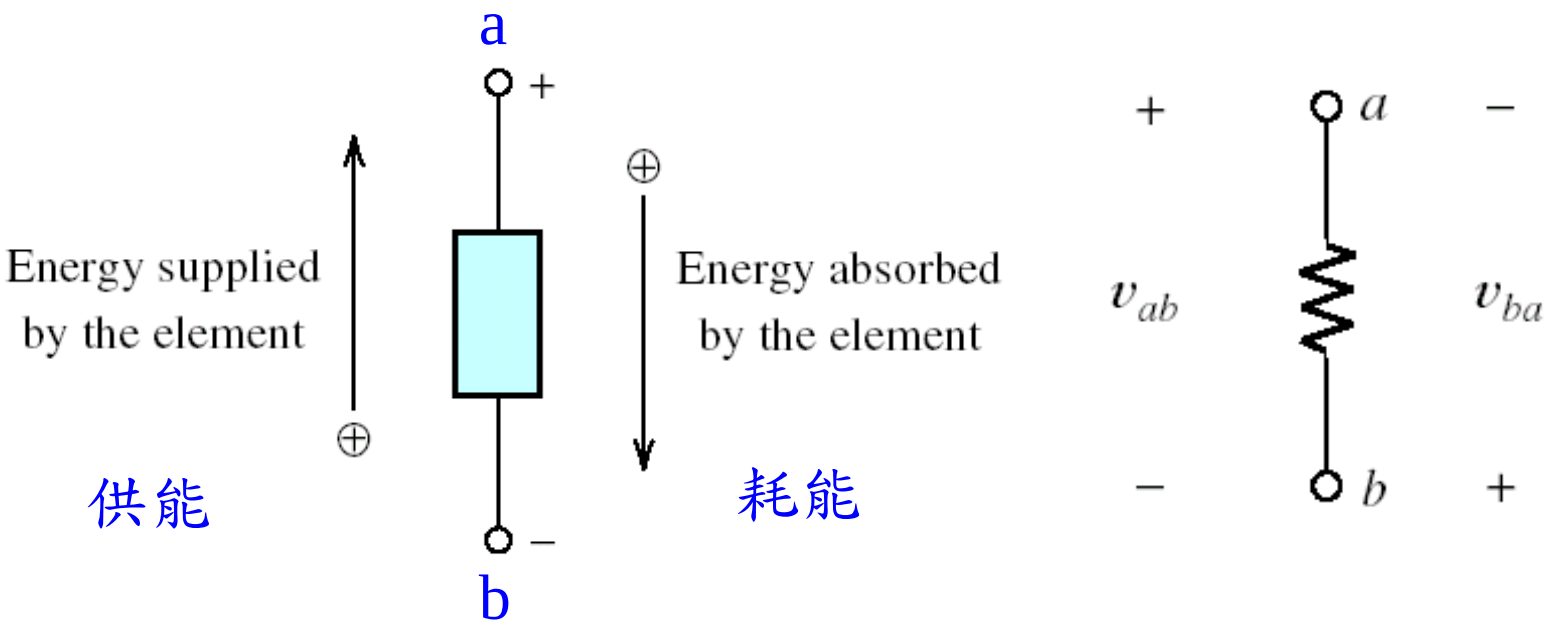
i_{ab}: 由 a 流到 b 的電流

Voltages (電壓)

- The **voltage:** 將單位電荷(unit of charge)由電路元件一端移動至另一端所產生的能量消耗(transferred energy)。

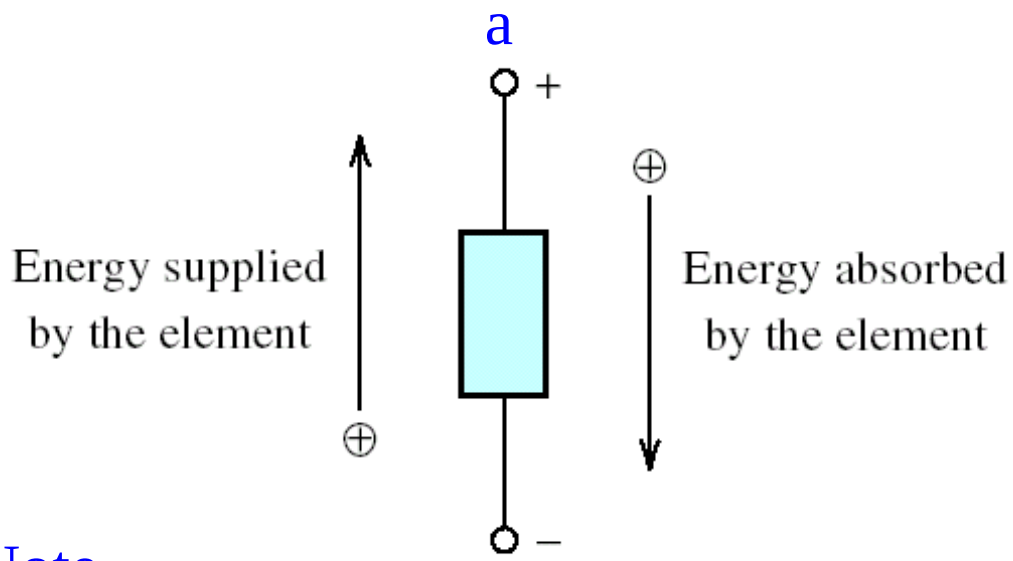
- Voltage 單位: volts (V), joules per coulomb (J/C, 焦耳/庫侖)

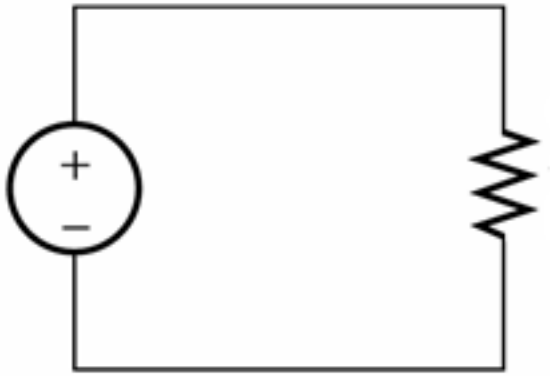
Voltage Direction



- V_{ab}: 代表將單位電荷由 端點 a 移動到端點 b 的能量轉換，$V_{ab} = -V_{ba}$ 。
- 正電荷由元件+端移動至−端代表元件消耗能量。
- 正電荷由元件− 端移動至+端代表元件提供能量。

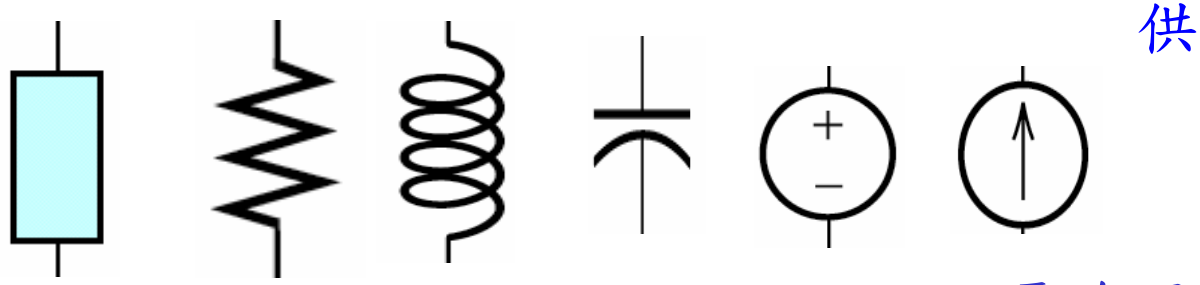
Voltage Direction





供能　　耗能

Note



電阻　電感　電容　電壓源　電流源

元件符號可廣泛代表各種不同電路元件

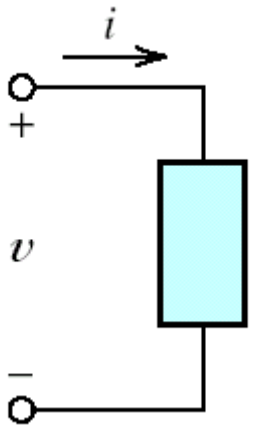
Note

Voltage is measured across the ends (兩端) of a circuit element.

Current is a measure of charge flow through the element.

1.3 POWER (功率) AND ENERGY(能量)

- 能量 (energy) : 焦耳(J)
- 功率(power) p : 單位時間消耗的能量 J/sec, 單位為瓦特(W, watt)
- i = C/sec, v = J/C,



$$\Longrightarrow \quad p(t) = v(t)i(t)$$

- 總能量消耗 w (energy between t_1 and t_2)

$$w = \int_{t_1}^{t_2} p(t)d(t)$$

(J, 焦耳)

Prefixes Physical Quantities

Prefix	Abbreviation	Scale Factor
giga-	G	10^{9}
meg- or mega-	M	10^{6}
kilo-	k	10^{3}
milli-	m	10^{-3}
micro-	μ	10^{-6}
nano-	n	10^{-9}
pico-	p	10^{-12}
femto-	f	10^{-15}

1.4 KIRCHHOFF'S CURRENT LAW (KCL)

1. 流入節點(node)的淨電流(net current)為0.
2. 流出節點的淨電流為0.
3. 流入節點的電流和 =流出節點的電流和。

node

Note: 節點代表電路上某一點上有兩個或以上的電路元件交會。

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

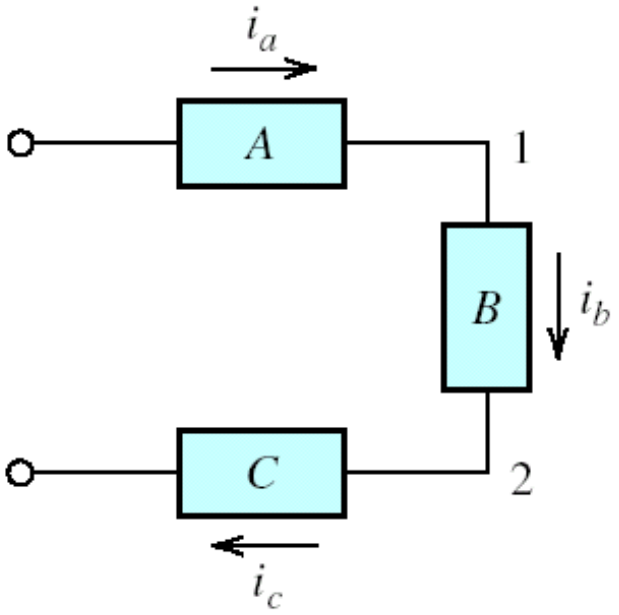
KIRCHHOFF'S CURRENT LAW (KCL)

1. $i_1 + i_2 + (-i_3) = 0$
2. $-i_1 + (-i_2) + i_3 = 0$
3. $i_1 + i_2 = i_3$

Node **a**

遵守電荷守恆定律

串聯電路 (series circuits)



Node 1 $i_a = i_b$

Node 2 $i_b = i_c$

$\Rightarrow$ $i_a = i_b = i_c$

串聯電路上電流相等

Excise 1.7 Use KCL to find the unknown currents in Fig. 1.21

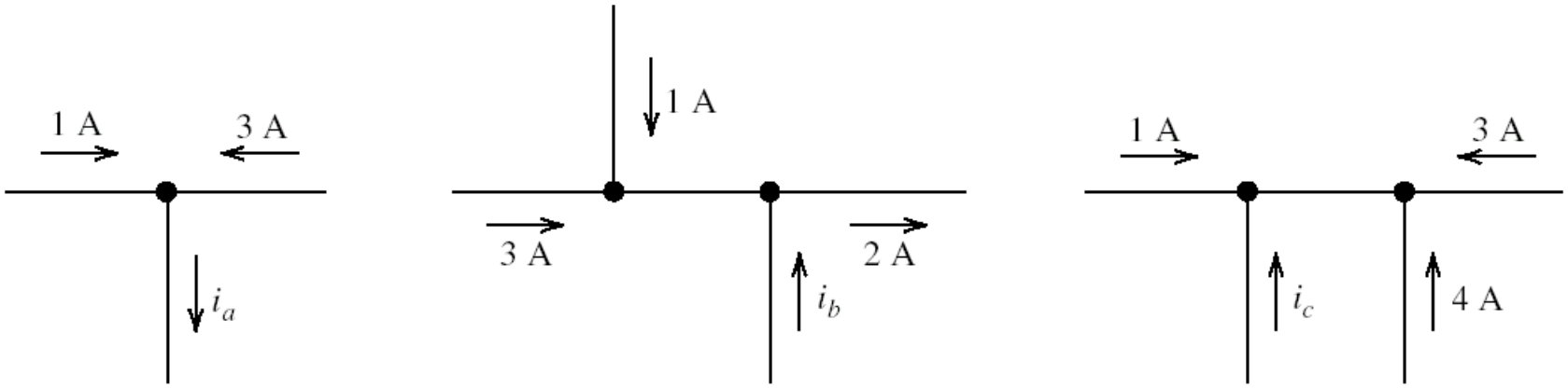
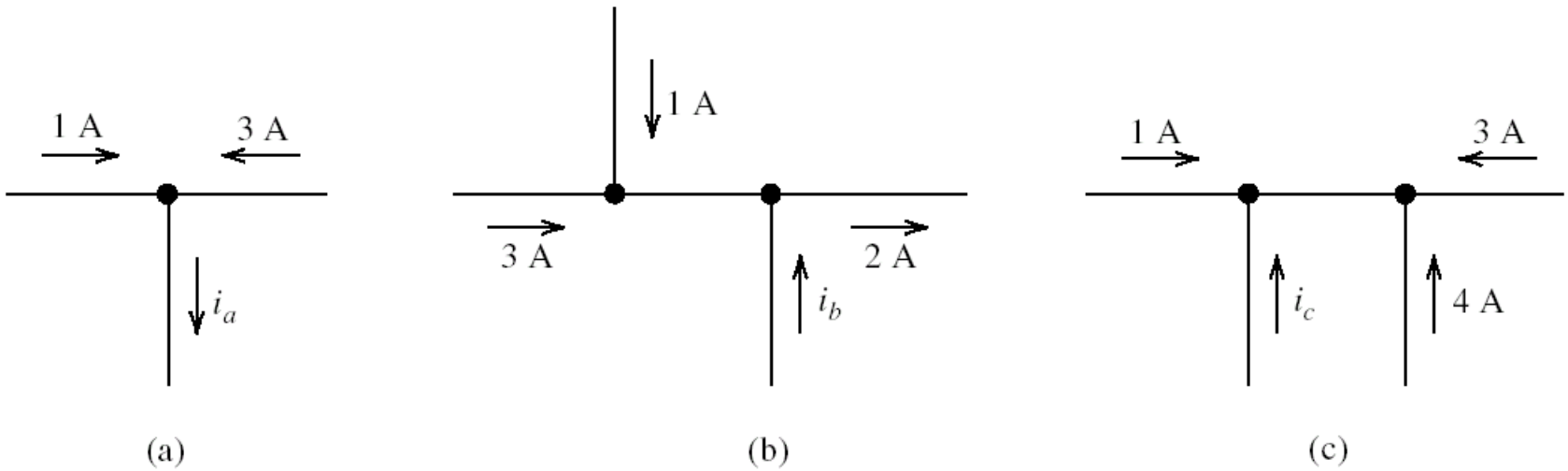


Figure 1.21 See Exercise 1.7.



E1.7 (a) Sum of currents leaving = Sum of currents entering

$i_a = 1 + 3 = 4$ A

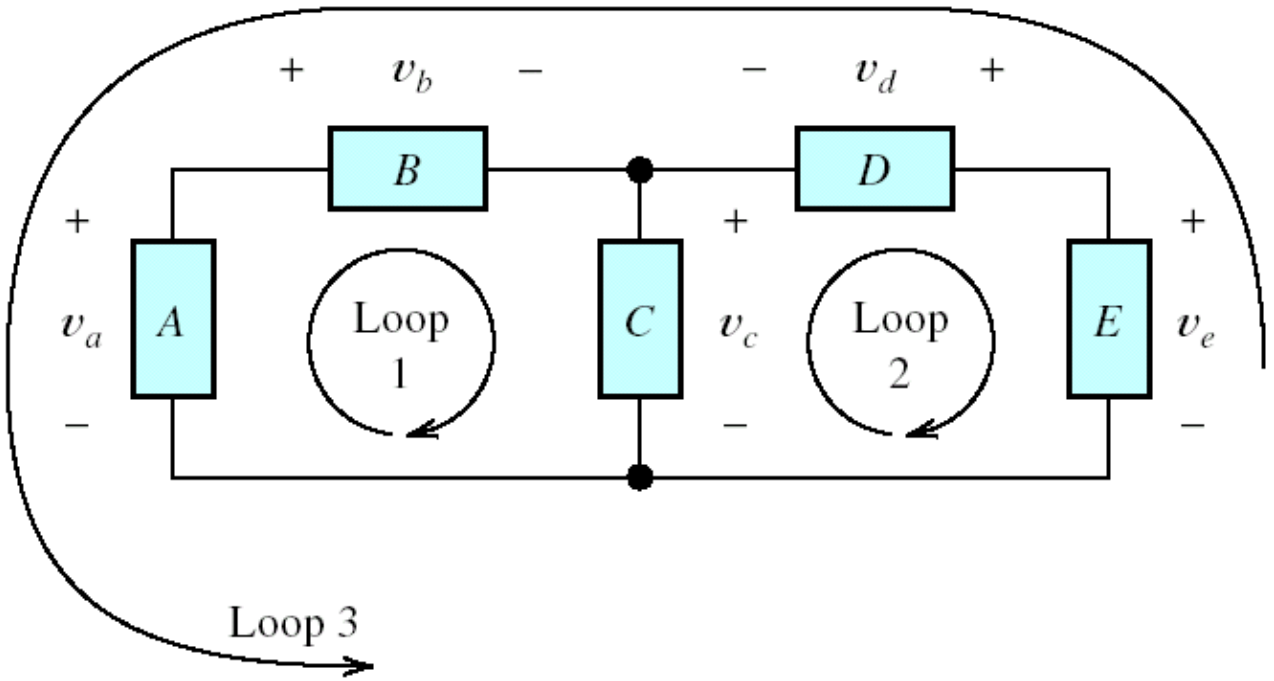
(b) $2 = 1 + 3 + i_b \quad \Rightarrow \quad i_b = -2$ A

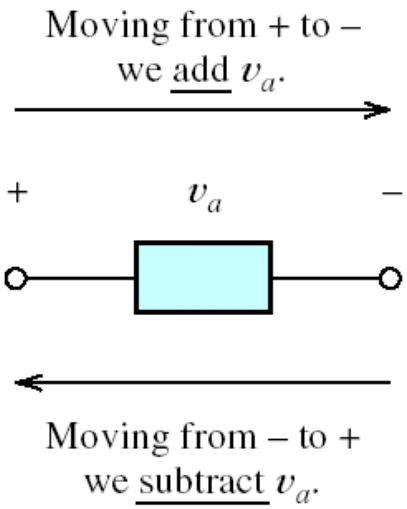
(c) $0 = 1 + i_c + 4 + 3 \quad \Rightarrow \quad i_c = -8$ A

1.5 KIRCHHOFF'S VOLTAGE LAW (KVL)

- 在電路上的任何封閉迴路(closed loop)，其電壓總和為零.

Note: 迴路(loop)代表起始於一個節點通過電路元件而回到此節點的封閉路徑(close path)。





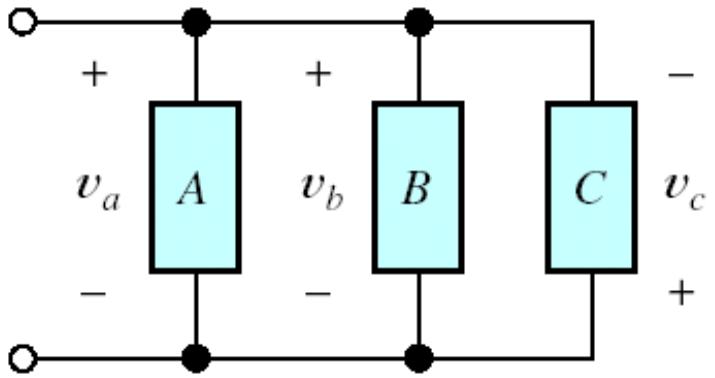
Loop 1 $\quad -v_a + v_b + v_c = 0$

Loop 2 $\quad -v_c - v_d + v_e = 0$

Loop 3 $\quad v_a - v_b + v_d - v_e = 0$

遵守能量守恆定律

並聯電路 (parallel circuits)



$$\text{L1} \quad -v_a + v_b = 0$$

$$\text{L2} \quad -v_b + (-v_c) = 0$$

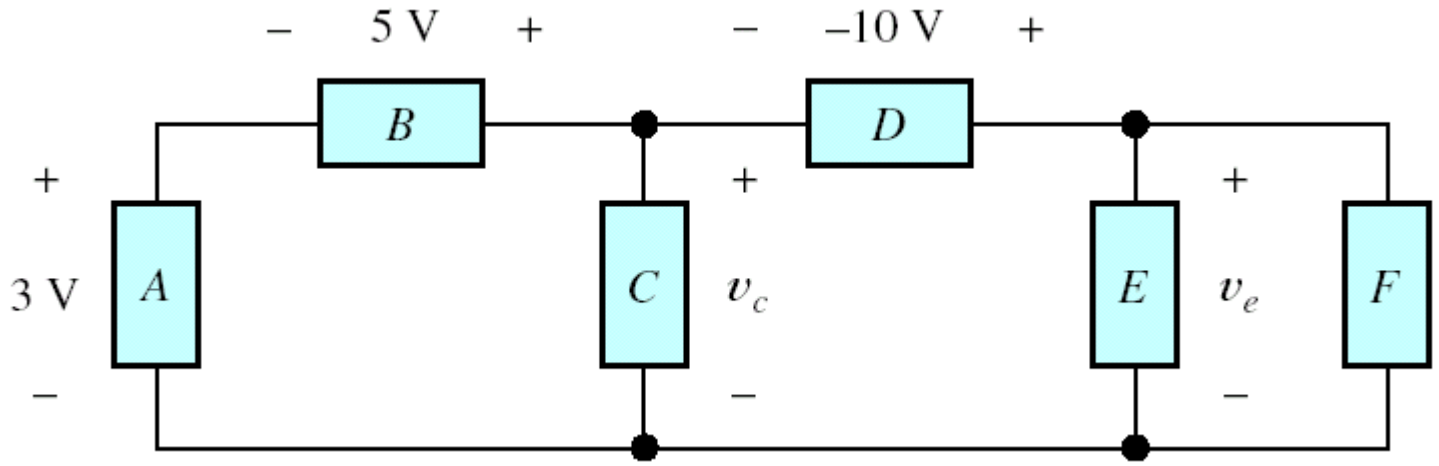
$$\Rightarrow \quad v_a = v_b = -v_c$$

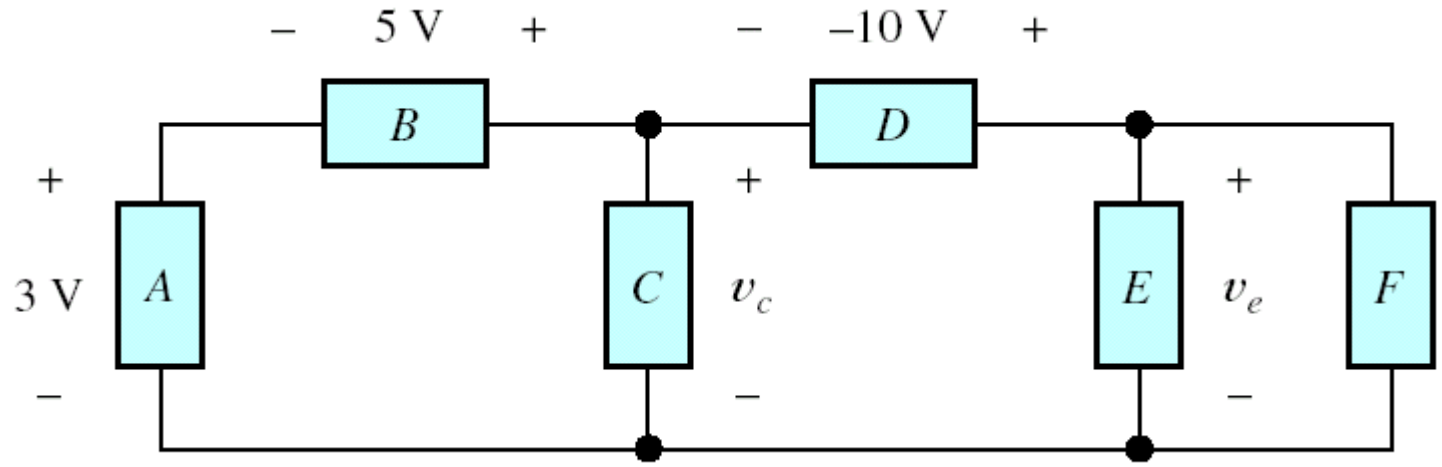
並聯電路上電壓相等

Excise 1.9 Using KVL to find v_c & v_e

Excise 1.10 Identify elements that are in parallel.

Identify elements that are in series.





E1.9 Go clockwise around the loop consisting of elements *A*, *B*, and *C*:

$-3 - 5 + v_c = 0 \quad \Rightarrow \quad v_c = 8$ V

Then go clockwise around the loop composed of elements *C*, *D* and *E*:

$- v_c - (-10) + v_e = 0 \quad \Rightarrow \quad v_e = -2$ V

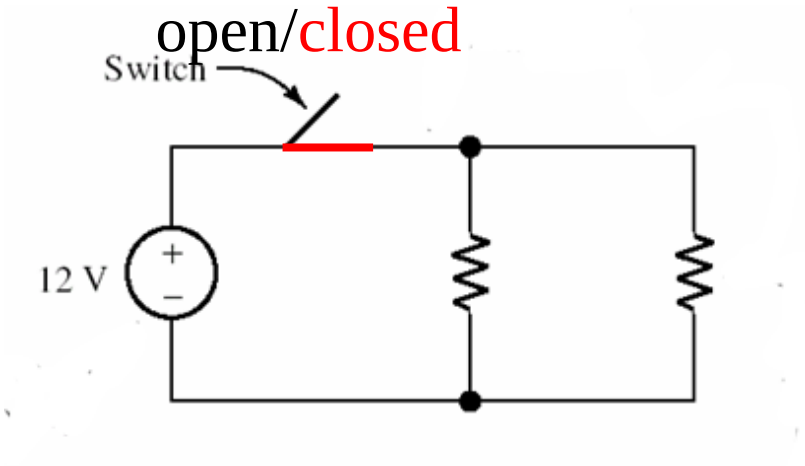
E1.10 Elements *E* and *F* are in parallel; elements *A* and *B* are in series.

1.6 Circuit Elements

- Conductors (導體)
- Voltage sources (電壓源)
- Current source (電流源)
- Resistors (電阻)

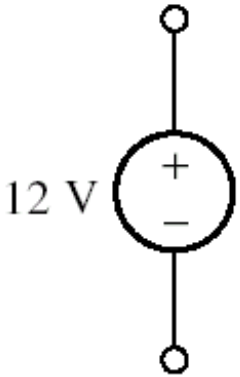
Conductors (導體)

- 電流通過理想導體(ideal conductors) 兩端的電壓為0.
- 電路兩點由導體連接稱為shorted circuit (短路)，可視為一個 node.
- 電路兩端不由導體或電路元件連接稱為斷路(open circuit).

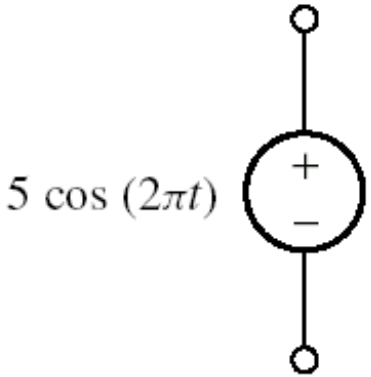


Ideal Voltage Source (理想電壓源)

- 理想(獨立)電壓源 (ideal independent voltage source)在兩端維持特定電壓，並且不受其他電路元件的影響。
- 在電路上以圓圈表示。



(a) Constant or dc voltage source



(b) Ac voltage source

DC

AC

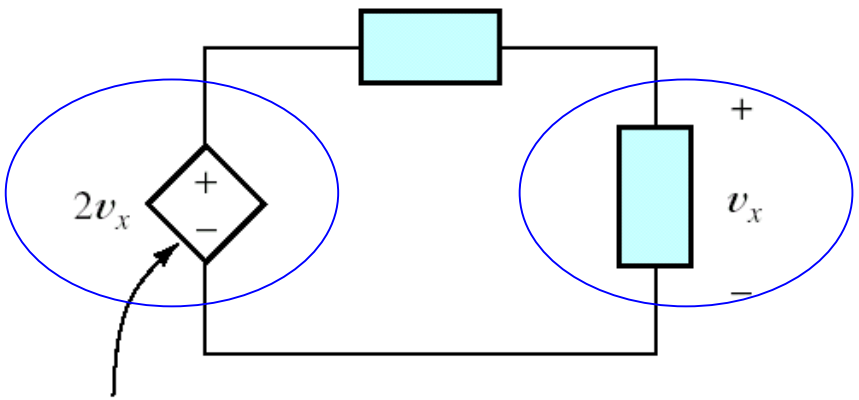
Dependent Voltage Source (相依電壓源)

- 相依電壓源(dependent voltage source)兩端的電壓是電路上其他電壓或電流的函數，又稱為受控電壓源(controlled voltage source)。
- 可分為
  - 電壓相依(voltage-controlled)電壓源
  - 電流相依(current-controlled)電壓源
- 以菱形符號表示。

相依電壓源

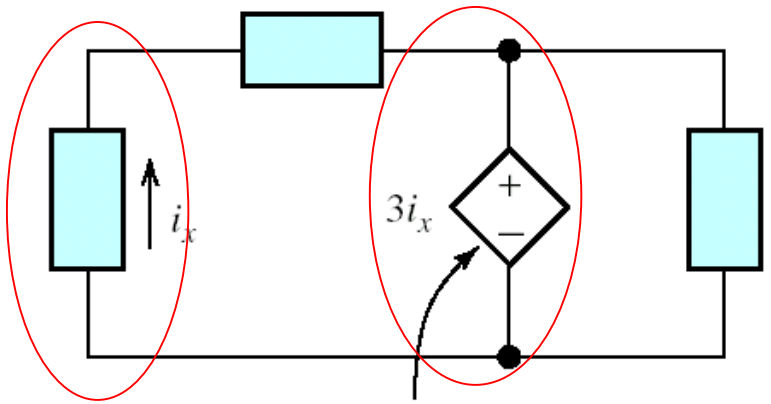
電壓/電流控制電壓源

- 電壓控制電壓源(voltage-controlled voltage source)兩端的電壓是電路上其他電路元件電壓的函數。
- 電流控制電壓源(current-controlled voltage source)兩端的電壓是電路上流過其他元件電流的函數。



Voltage-controlled voltage source

(a)



Current-controlled voltage source

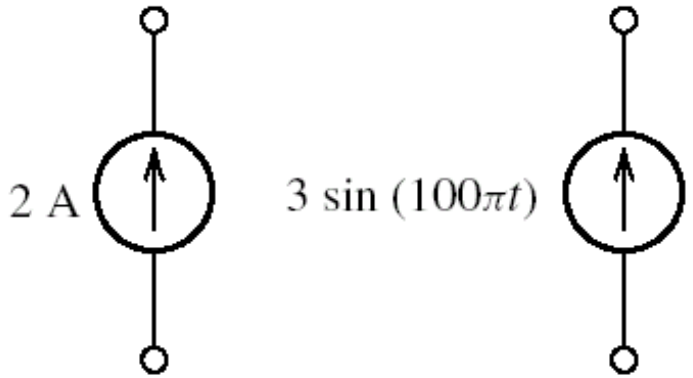
(b)

增益函數 (gain factor)=2 (V/V)

增益函數 = 3 (V/A)

Independent Current Sources (獨立電流源)

- 獨立電流源在兩端有特定電流流過，並且不受其他電路元件的影響。
- 在電路上以圓圈表示，並以箭頭表示電流方向。



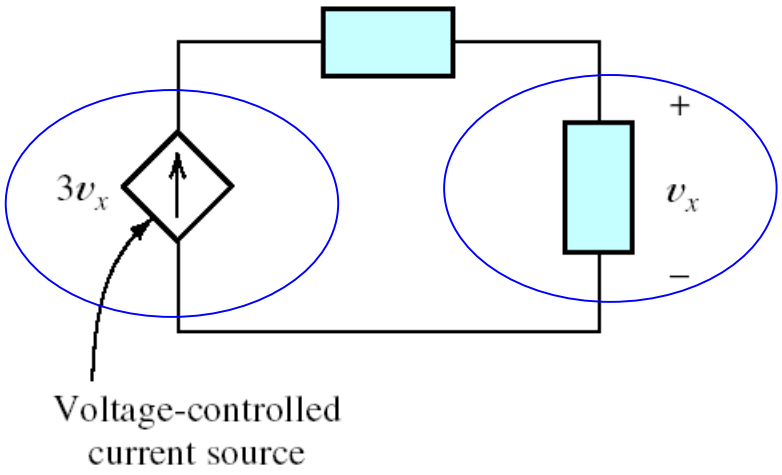
(a) Dc current source　　(b) Ac current source

Dependent Current Source (相依電流源)

- 相依電壓源(dependent voltage source)兩端流通的電流是電路上其他電壓或電流的函數，又稱為受控電流源(controlled current source)。
- 可分為
  - 電壓相依電流源
  - 電流相依電流源
- 以菱形符號表示。

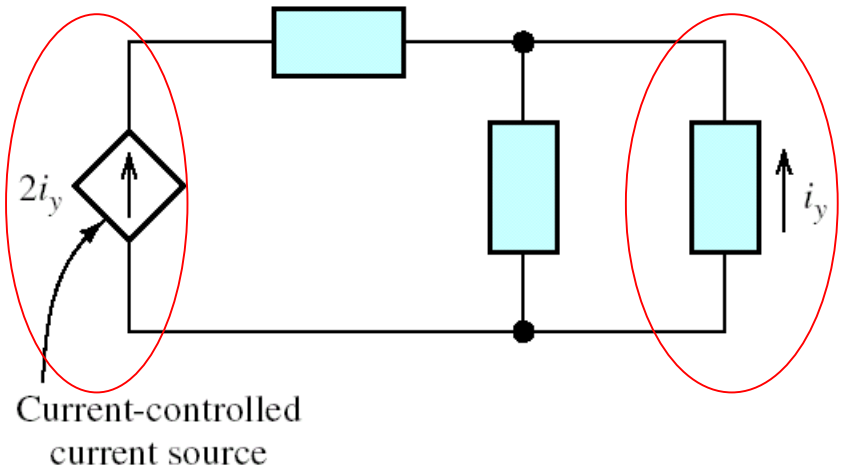
相依電流源

電壓/電流控制電流源



(a)

增益函數 (gain factor)=3 (A/V)



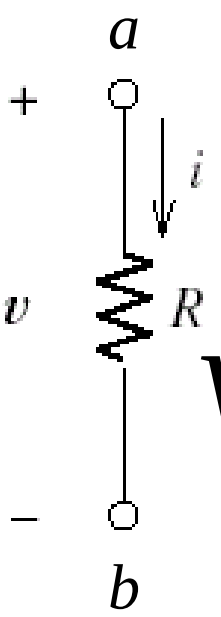
(b)

增益函數 = 2 (A/A)

電阻 (Resistor)

- 電阻兩端的電壓與電流比值為常數。
- 歐姆定律(Ohm's law)

$$v = iR$$ 歐姆 Ω (V/A)



$$v_{ab} = i_{ab}R$$

- Passive reference configuration電流由元件電壓的正極流入。在這種組態下，定義此電路元件的功率為正值，代表能量被此元件吸收。

電導 (Conductance)

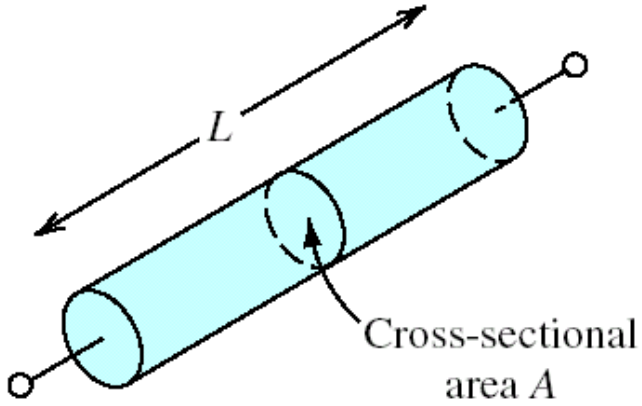
$$i = \frac{1}{R} v$$

$$G = \frac{1}{R}$$ (電導) siemens Ω^{-1}(A/V)

$$i = Gv$$

電阻之物理參數與功率

- 電阻的大小與導線的長度成正比，截面積成反比，我們可以寫成

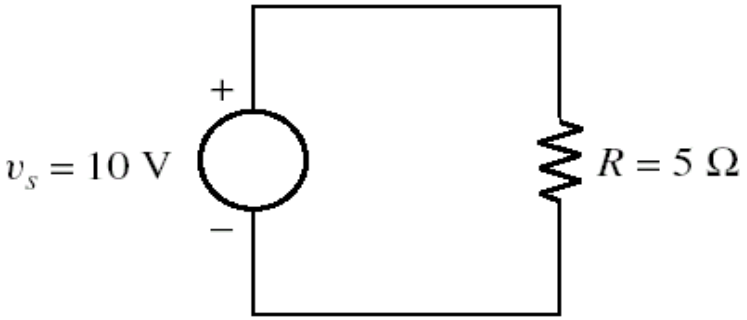


$$R = \frac{\rho L}{A}$$

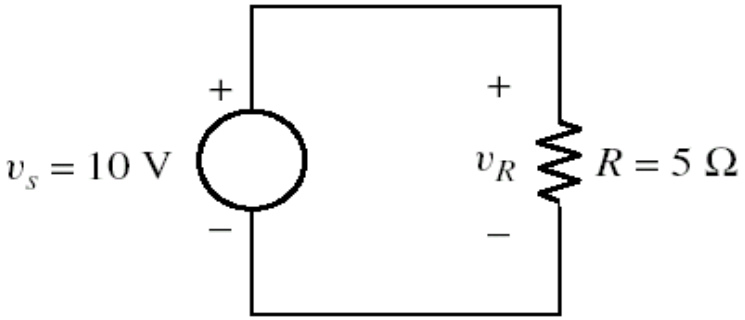
- ρ 代表電阻材料之電阻系數 (resistivity)
- 功率消耗

$$p = vi = Ri^2 = \frac{v^2}{R}$$

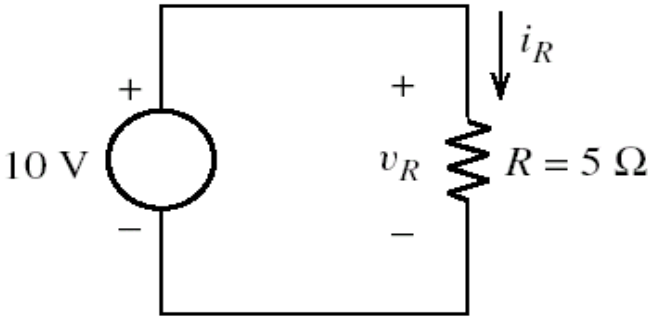
1.7 Introduction to Circuits



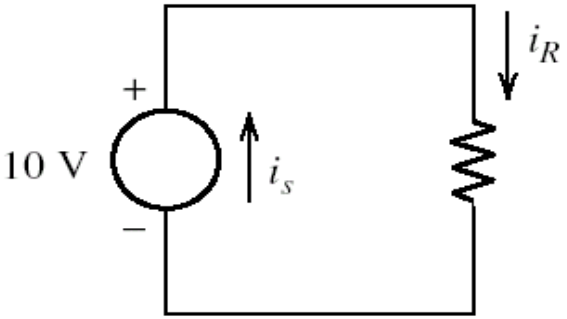
(a) Circuit diagram



(b) KVL requires that $v_R = 10$ V



(c) Ohm's law yields $i_R = v_R/R = 2$ A

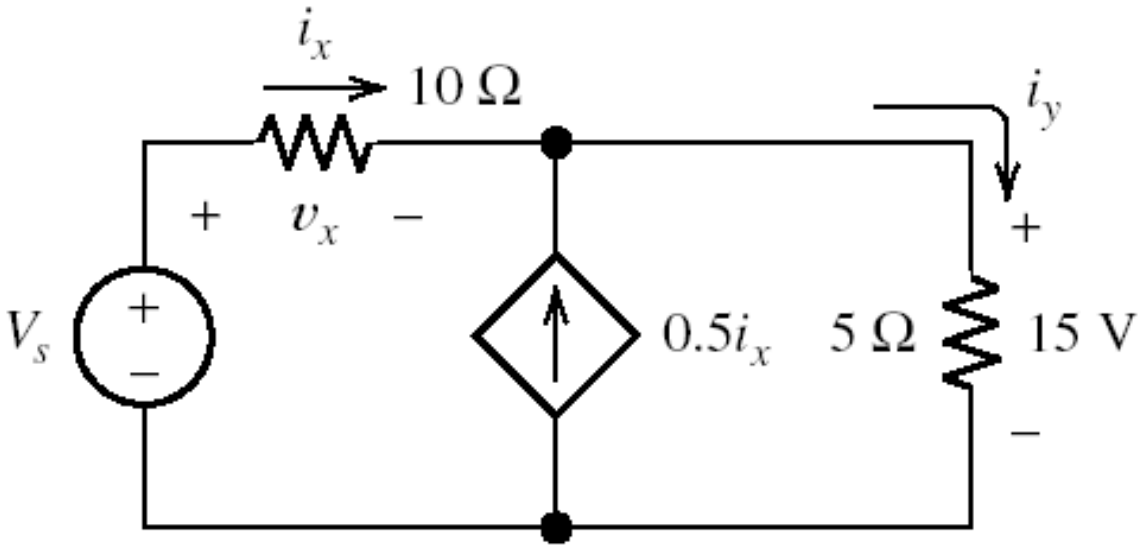


(d) KCL requires that $i_s = i_R$

$$p_R = v_R i_R = i_R^2 R = \frac{v_R^2}{R} = 20\text{W}$$

$$p_s = -20\text{W}$$

Using KVL, KCL, and Ohm's Law to Solve a Circuit



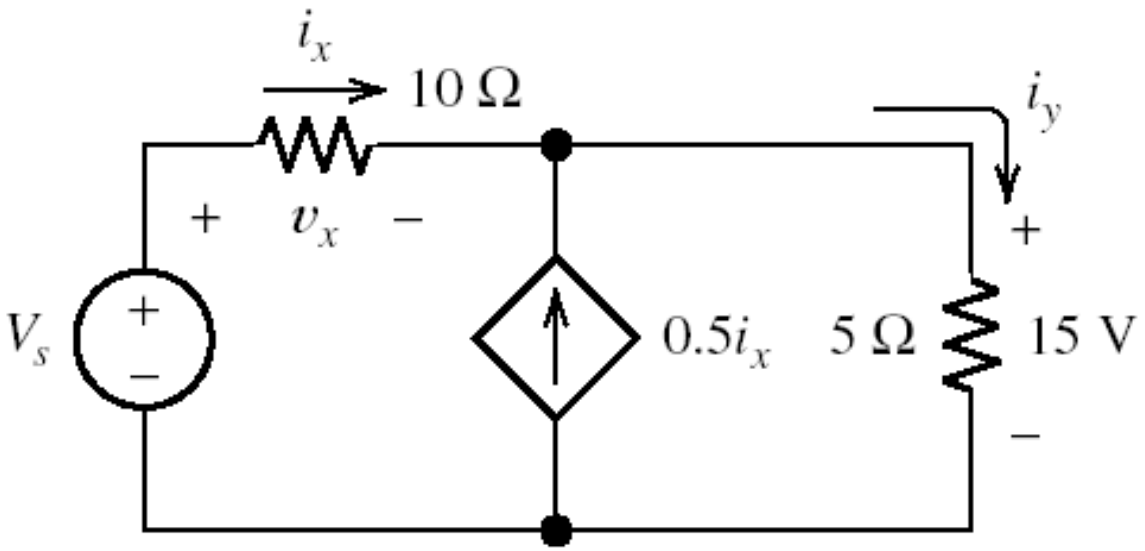
Ohm's Law

$$i_y = \frac{15\,\text{V}}{5\,\Omega} = 3\,\text{A}$$

KCL

$$i_x + 0.5i_x = i_y$$

$$i_x = 2\,\text{A}$$



Ohm's Law

$$v_x = 10 i_x = 20 \text{ V}$$

KVL

$$V_s = v_x + 15$$

$$V_s = 35 \text{ V}$$