Chapter 3
Inductance and Capacitance
電感與電容

Inductance and Capacitance
電感與電容

- 電容與電感皆可用來儲存能量(energy-storage elements)，並將儲存的能量釋放回電路。
- 電容與電感無法自行產生能量，故稱為被動元件(passive elements,如同電阻)。
- 電容是根據電場現象製造的電路元件，將能量儲存於電場。
- 電感是依磁場現象製造的電路元件，將能量儲存於磁場。

Inductance and Capacitance
電感與電容

- 電容與電感皆具有線性微分的端點特性
  - 理想電容兩端電流與電壓對時間微分成正比
  - 理想電感兩端電壓與電流對時間微分成正比

3.1 CAPACITANCE (電容)

•電容器是由絕緣材料(dielectric,介電質)隔開的兩片導電平板(conductive plates)形成。

•介電質為mica (雲母), polyester(聚脂) 等絕緣材料.

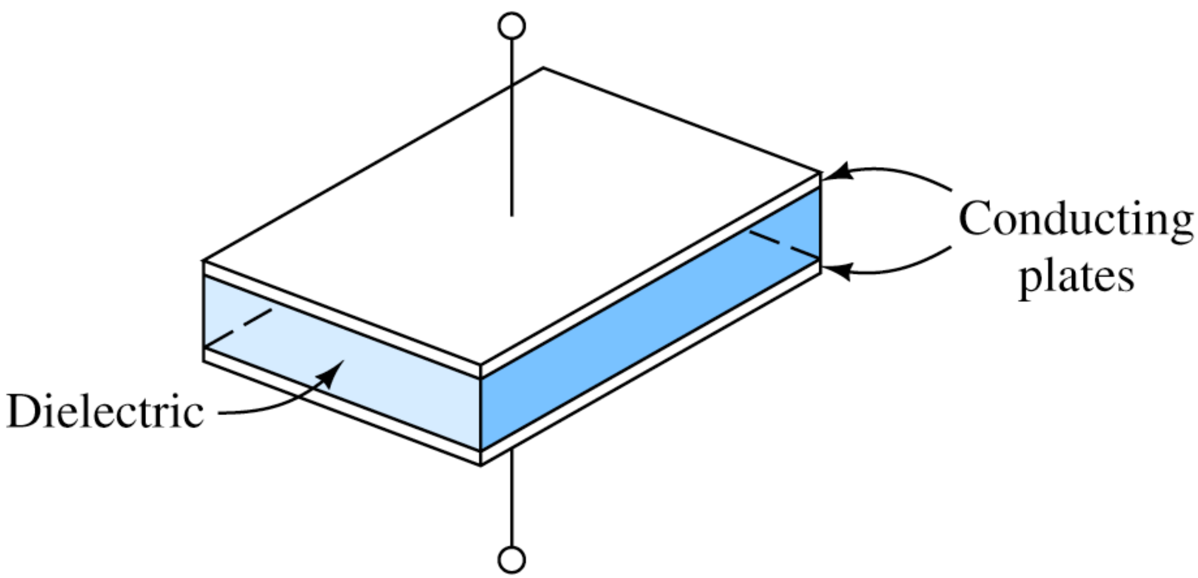
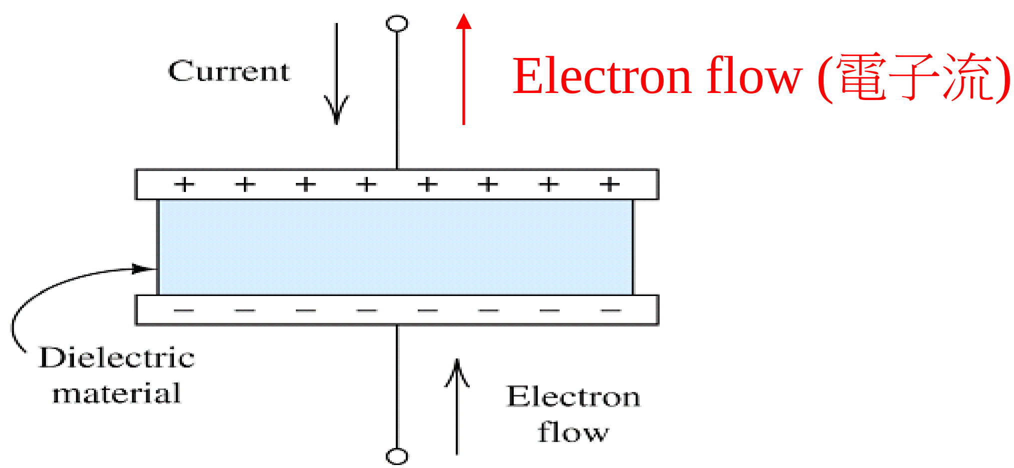


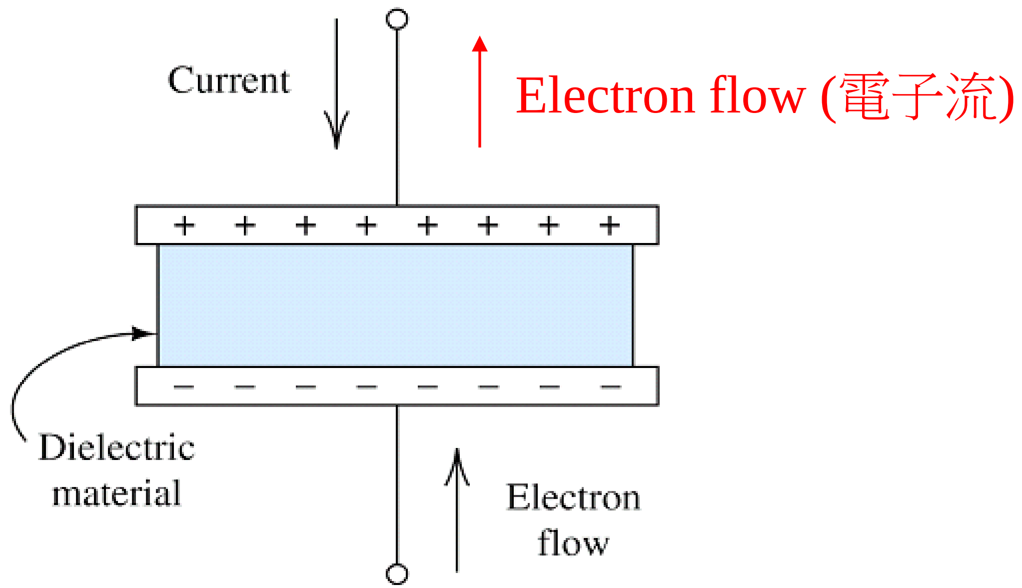
Figure 3.1 A parallel-plate capacitor consists of two conductive plates separated by a dielectric layer.

•在電容器的兩電板間加上電壓，因介電值的存在，導線電荷無法直接流經電板。
•電荷聚集在兩導電平板上。如下圖，由下往上移動的負電荷電子(electrons)聚集在下導電平板，使下導電平板帶負電，而形成電場。
•此電場使上導電平板的電子往上移動(正電荷聚集於上導電平板，而將電子往上推)。



(a) As current flows through a capacitor, charges of opposite sign collect on the respective plates

•聚集在下導電平板的電子數等於離開上導電平板的電子數，可視為電流流過電容。
•兩導電平板上電荷數相等，符號相反。



(a) As current flows through a capacitor, charges of opposite sign collect on the respective plates

Stored Charge in Terms of Voltage

- 理想電容儲存的電荷(charge) q 與其導電平板兩端電壓成正比。

$$q = Cv$$

- 常數C為電容值(capacitance)，單位為法拉(F, farads)，等於coulombs/volt (C/V) 。
- 電荷 q 代表接電壓正端的導電平板上的淨(正)電荷。
- 一般電容值在數個pico法拉(1pF= 10^{-12}F)到0.01F之間

Current in Terms of Voltage

Recall 電流： time rate of flow of electrical charge (單位時間通過電荷量)。電容兩端的電流為

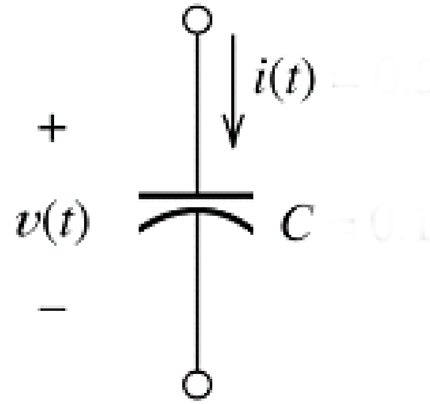
$$i = \frac{dq}{dt} = \frac{d}{dt}(Cv)$$

電容兩端電壓電流關係為

$$i = C\frac{dv}{dt}$$

若電壓上升，則有電流通過電容，而電荷累積在導電平板上。若電壓不變(DC)，則電流為0，視為斷路(open circuit)，平板電荷數不變。

Symbol for Capacitance

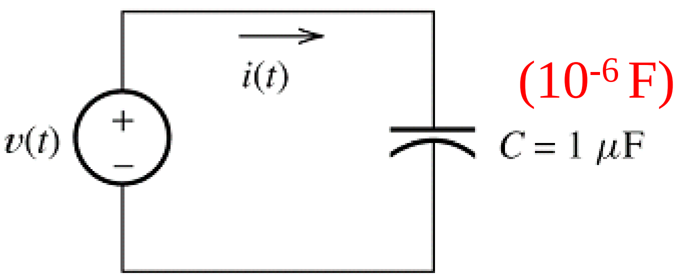


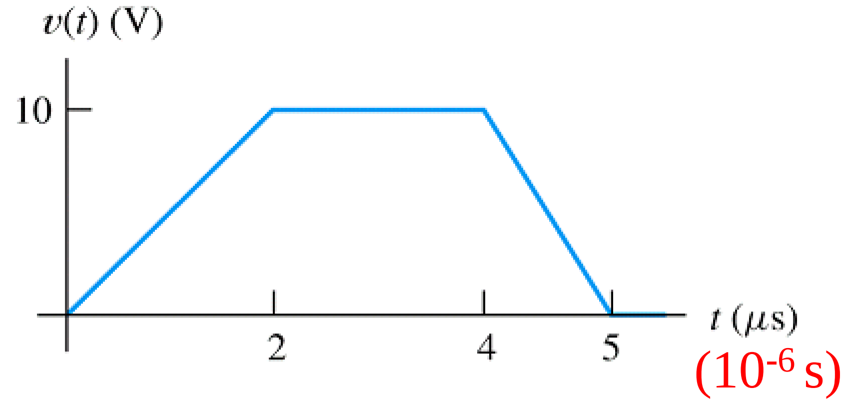
•通過電容的電流參考方向為電容器兩端電壓降落的方向(由正極流入，負極流出)，具 passive configuration特性。

•若電容放電，則

$$i = -C\frac{dv}{dt}$$

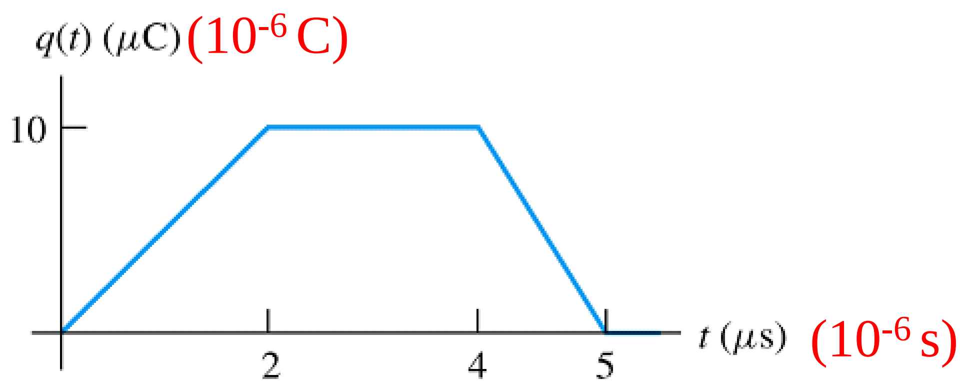
Example 3.1 Plot the stored charge and the current through the capacitance versus time.



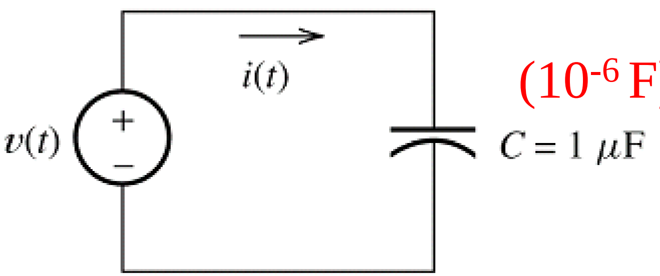


The stored charge

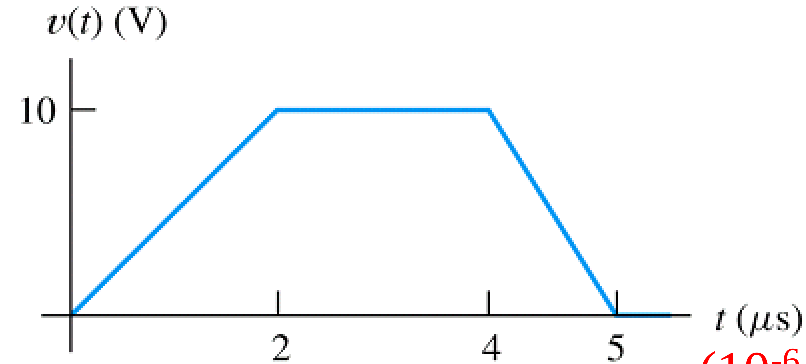
$$q(t) = Cv(t) = 10^{-6}v(t)$$



Example 3.1 Plot the stored charge and the current through the capacitance versus time.



(10^{-6} F)



(10^{-6} s)

The current

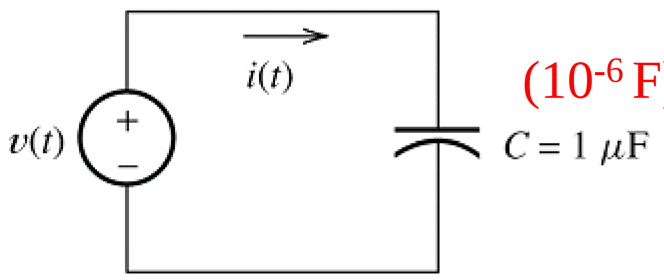
$$i(t) = \frac{dq(t)}{dt} = C\frac{dv(t)}{dt} = 10^{-6}\frac{dv(t)}{dt}$$

$t = 0 \sim 2us$ $\quad \frac{dv(t)}{dt} = \frac{10V}{2\times 10^{-6}s} = 5\times 10^{6} V/s \quad i(t) = C\frac{dv(t)}{dt} = 10^{-6}\times 5\times 10^{6} = 5A$

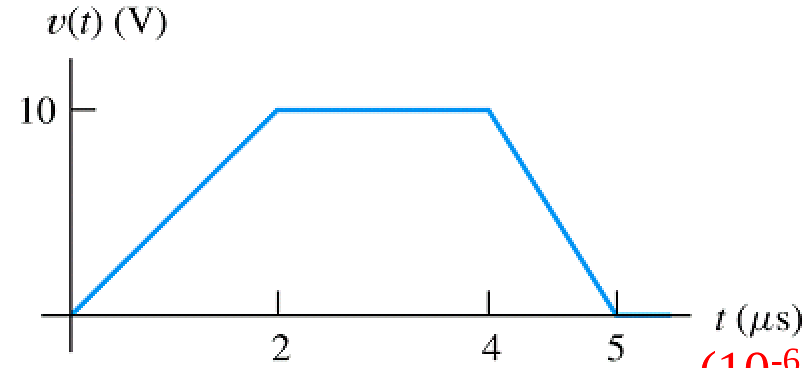
$t = 2 \sim 4\ us$ $\quad \frac{dv(t)}{dt} = 0 \quad i(t) = C\frac{dv(t)}{dt} = 0$

$t = 4 \sim 5\ us$ $\quad \frac{dv(t)}{dt} = \frac{-10V}{10^{-6}s} = -10^{7} V/s \quad i(t) = C\frac{dv(t)}{dt} = 10^{-6}\times(-10^{7}) = -10A$

Example 3.1 Plot the stored charge and the current through the capacitance versus time.



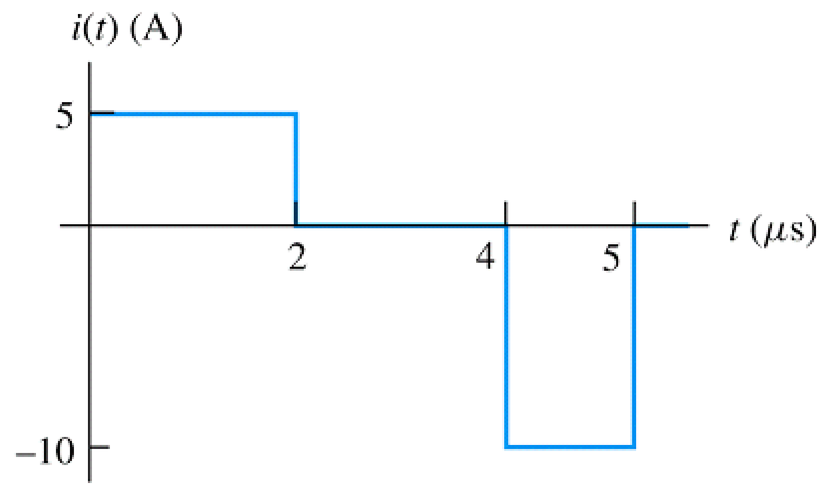
(10^{-6} F)



(10^{-6} s)

The current

$$\begin{cases} t = 0\sim2us & i(t) = 5A \\ t = 2\sim4\ us & i(t) = 0 \\ t = 4\sim5\ us & i(t) = -10A \end{cases}$$



Voltage in Terms of Current

- 假設我們知道通過電容C的電流$i(t)$，如何求得電容器兩端電壓？假設初始時間t_0時初始電荷為q(t_0)。

$$i = \frac{dq}{dt} \quad \Rightarrow \quad q(t) = \int_{t_0}^{t} i(t)dt + q(t_0)$$

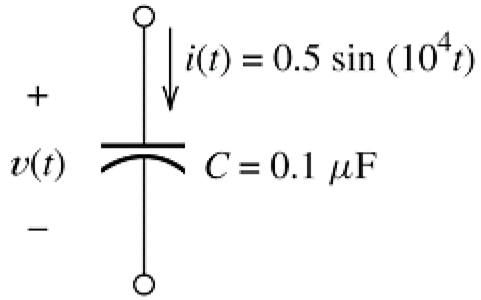
$$q(t) = Cv(t) \quad \Rightarrow \quad v(t) = \frac{1}{C}q(t) = \frac{1}{C}\int_{t_0}^{t} i(t)dt + \frac{q(t_0)}{C}$$

Initial voltage $$v(t_0) = \frac{q(t_0)}{C}$$

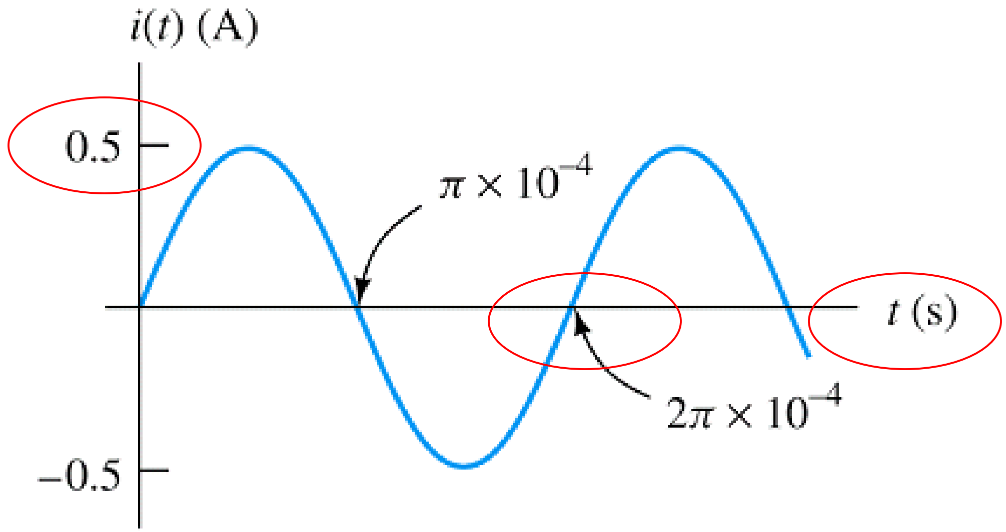
$$\Rightarrow \quad v(t) = \frac{1}{C}\int_{t_0}^{t} i(t)dt + v(t_0)$$

Example 3.2 Determining Voltage Given Current

C=0.1 *u*F, *q*(0)=0. After t_0=0, $i(t) = 0.5\sin(10^4 t)$. Plot *i*(*t*), *q*(*t*) and *v*(*t*).



1. Plot *i*(*t*)



Example 3.2 Determining Voltage Given Current

C=0.1 *u*F, *q*(0)=0. After t_0=0, $i(t)=0.5\sin(10^4 t)$. Plot *i*(*t*), *q*(*t*) and *v*(*t*).

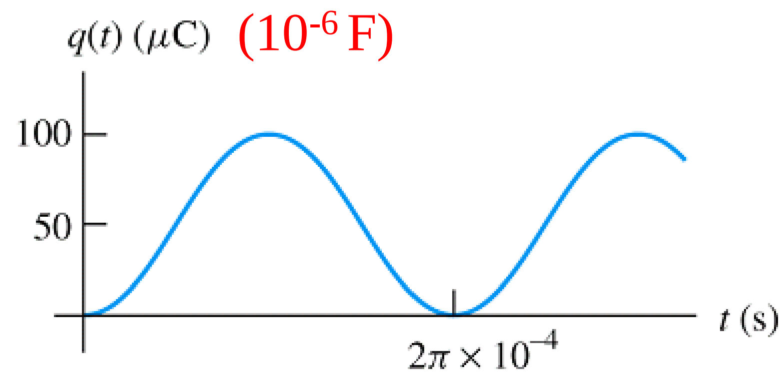
2. Determining *q*(*t*)

$$q(t)=\int_0^t i(t)dt+q(0)$$

$$=\int_0^t 0.5\sin(10^4 t)dt$$

$$=-0.5\times10^{-4}\cos(10^4 t)\Big|_0^t$$

$$=0.5\times10^{-4}[1-\cos(10^4 t)]$$



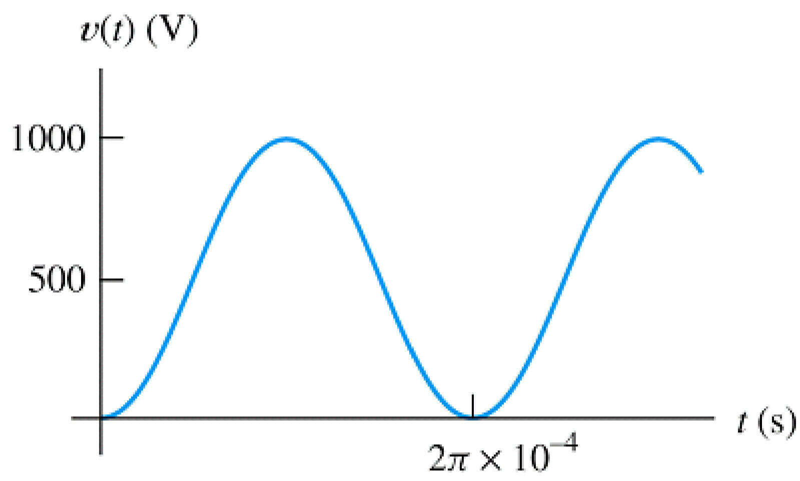
Example 3.2 Determining Voltage Given Current

C=0.1 *u*F, $q(0)=0$. After t_0, $i(t) = 0.5\sin(10^4 t)$ Plot $i(t)$, $q(t)$ and $v(t)$.

3. Determining $v(t)$

$$v(t) = \frac{q(t)}{C} = \frac{q(t)}{10^{-7}}$$

$$= 500[1 - \cos(10^4 t)]$$



Stored Energy

- 如何計算電容所儲存的能量(energy)?假設電容C的初始電壓$v(t_0) = 0$，$q\,(t_0) = 0$ ，電容器兩端電壓在t_0到t由0上升$v(t)$。

1. 計算power (單位時間消耗的能量 J/sec)

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

$$\because i = C\frac{dv}{dt} \quad \Longrightarrow \quad p(t) = Cv\frac{dv}{dt}$$

Stored Energy

2. 計算儲存能量

$$w(t) = \int_{t_0}^{t} p(t)dt$$

$$= \int_{t_0}^{t} Cv\frac{dv}{\cancel{dt}}\cancel{dt} \quad = \int_{0}^{v(t)} Cvdv$$

$$= \frac{1}{2}Cv^2\Big|_{0}^{v(t)} = \frac{1}{2}Cv^2(t)$$

Stored Energy

3. 儲存能量其他表示式

$$w(t) = \frac{1}{2} C v^2(t)$$

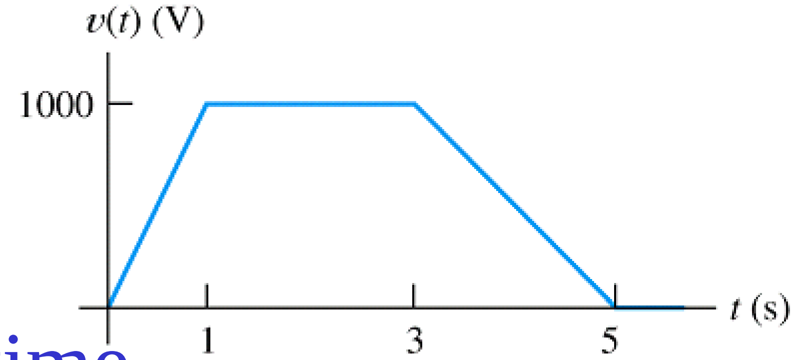
$$\because q(t) = C v(t) \quad \Rightarrow \quad w(t) = \frac{1}{2} v(t) q(t)$$

or

$$w(t) = \frac{q^2(t)}{2C}$$

Example 3.3 Current, Power, and Energy for a Capacitance

C=10 *u*F, *v*(*t*) is given. *q*(0)=0. Plot current, the power delivered and energy stored for *t* = 0~5 s.



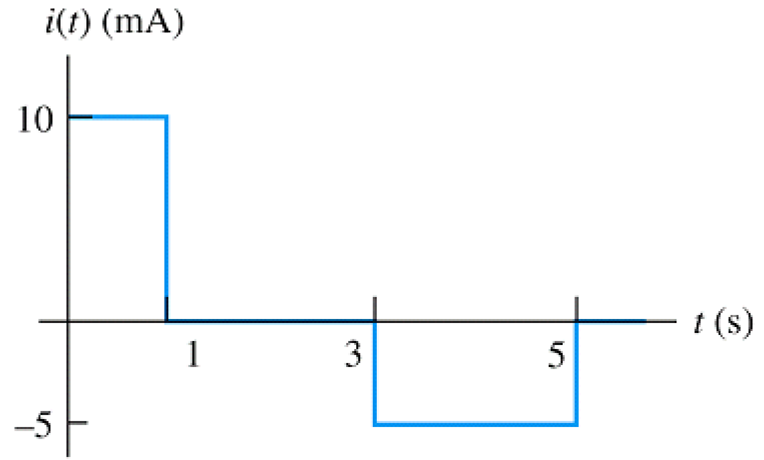
1. Express *v*(*t*) as a function of time

$$v(t)=\begin{cases} 1000tV & for \quad 0<t<1 \\ 1000V & for \quad 1<t<3 \\ 500(5-t)V & for \quad 3<t<5 \end{cases}$$

2. Calculate *i*(*t*)

$$i(t)=C\frac{dv(t)}{dt}$$

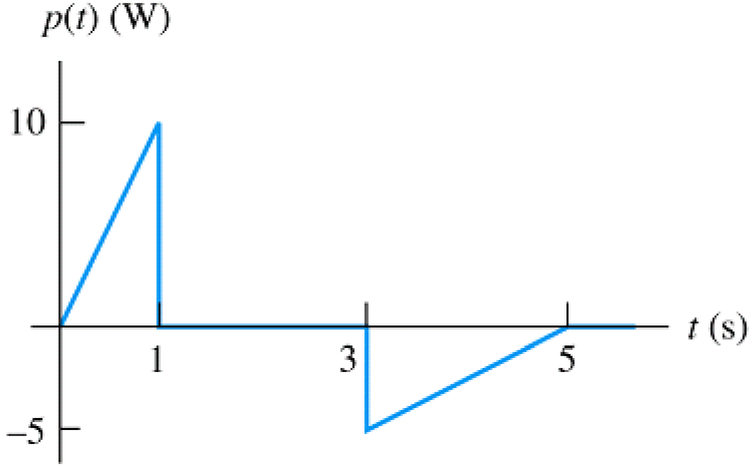
$$i(t)=\begin{cases} 10\times10^{-3}A & for \quad 0<t<1 \\ 0A & for \quad 1<t<3 \\ -5\times10^{-3}A & for \quad 3<t<5 \end{cases}$$



Example 3.3 Current, Power, and Energy for a Capacitance

$$v(t) = \begin{cases} 1000tV & for \quad 0 < t < 1 \\ 1000V & for \quad 1 < t < 3 \\ 500(5-t)V & for \quad 3 < t < 5 \end{cases} \qquad i(t) = \begin{cases} 10\times10^{-3}A & for \quad 0 < t < 1 \\ 0A & for \quad 1 < t < 3 \\ -5\times10^{-3}A & for \quad 3 < t < 5 \end{cases}$$

3. Calculate the power



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

$$p(t) = \begin{cases} 10tW & for \quad 0 < t < 1 \\ 0W & for \quad 1 < t < 3 \\ 2.5(t-5)W & for \quad 3 < t < 5 \end{cases}$$

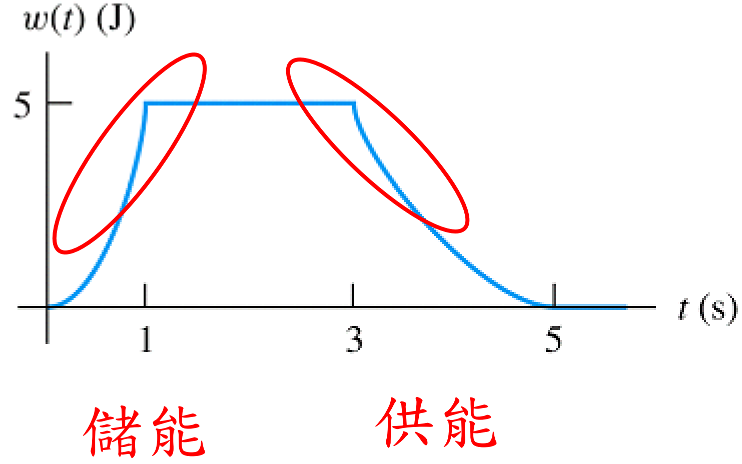
Example 3.3 Current, Power, and Energy for a Capacitance

$$v(t) = \begin{cases} 1000tV & for \quad 0 < t < 1 \\ 1000V & for \quad 1 < t < 3 \\ 500(5-t)V & for \quad 3 < t < 5 \end{cases}$$

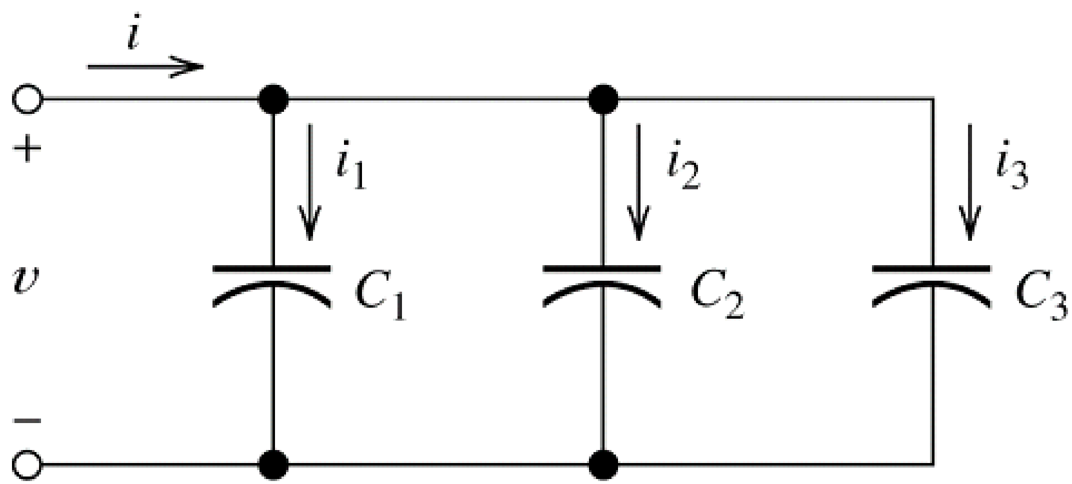
4. Calculate the energy

$$w(t) = \frac{1}{2}Cv^2(t) = 5\times10^{-6}v^2(t)$$

$$w(t) = \begin{cases} 5t^2 J & for \quad 0 < t < 1 \\ 5J & for \quad 1 < t < 3 \\ 1.25(5-t)^2 J & for \quad 3 < t < 5 \end{cases}$$



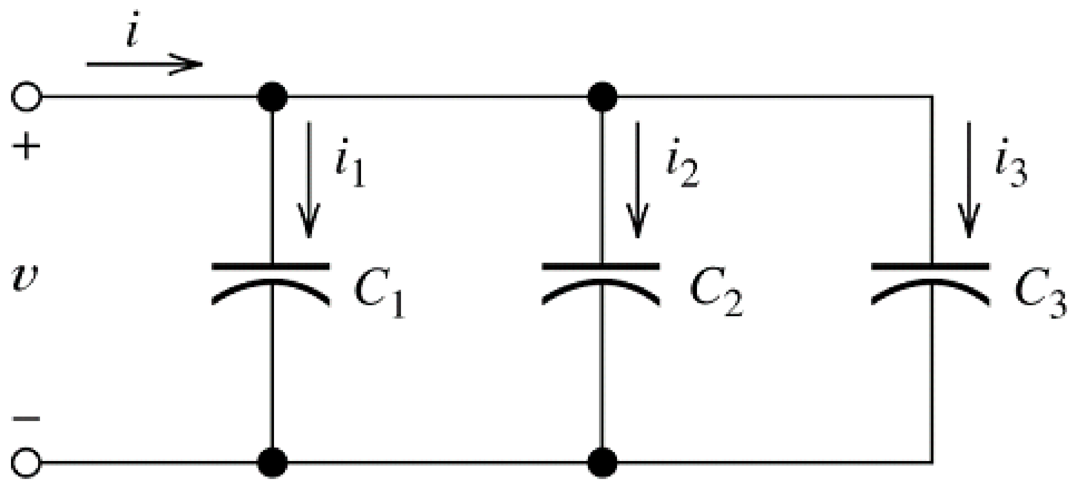
3.2 Capacitance in Series and Parallel



$$i = C\frac{dv}{dt}$$

$$i_1 = C_1\frac{dv}{dt} \qquad i_2 = C_2\frac{dv}{dt} \qquad i_3 = C_3\frac{dv}{dt}$$

Capacitance in Parallel



KCL

$$i = i_1 + i_2 + i_3$$

$$= C_1 \frac{dv}{dt} + C_2 \frac{dv}{dt} + C_3 \frac{dv}{dt}$$

$$= (C_1 + C_2 + C_3)\frac{dv}{dt}$$

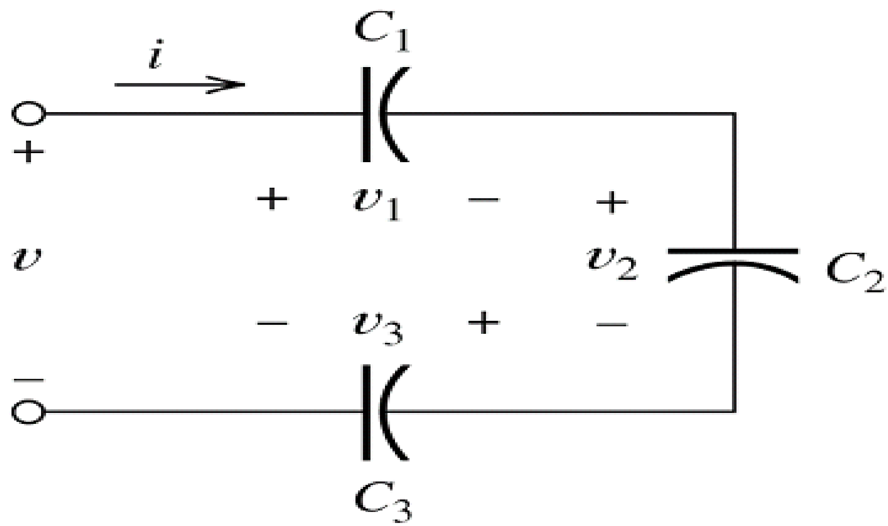
$$C_{eq} = C_1 + C_2 + C_3$$

$$i = C_{eq} \frac{dv}{dt}$$

電容並聯，等效電容值相加

Recall:電阻串聯，等效電阻值相加

Capacitance in Series

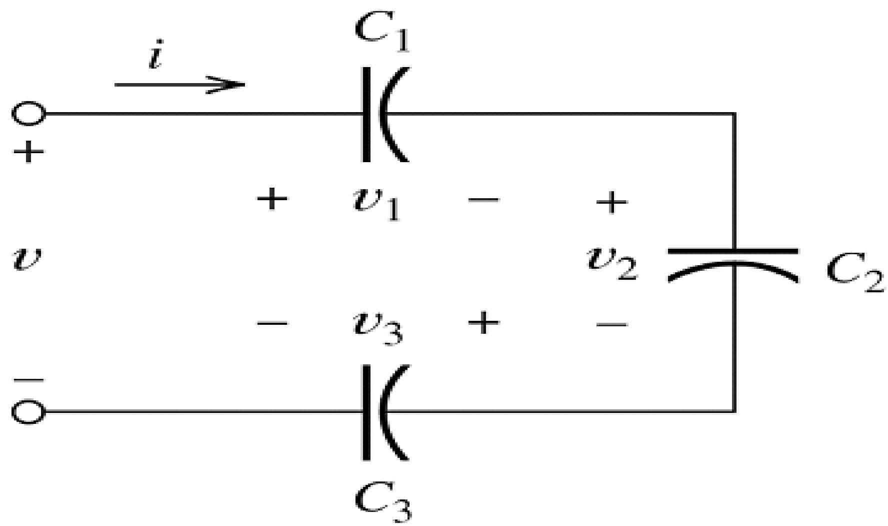


$$v(t) = \frac{1}{C}\int_0^t i(t)dt + v(t_0)$$

KVL

$$v = v_1 + v_2 + v_3$$

Capacitance in Series

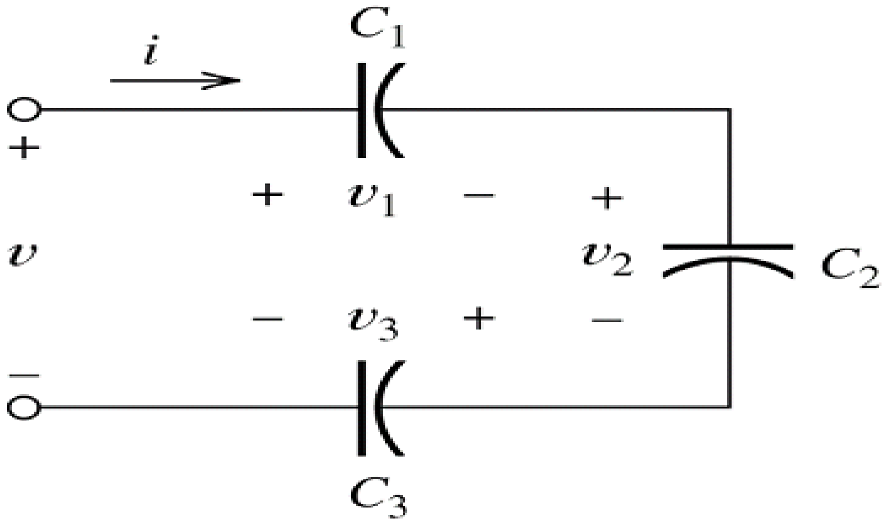


$$v(t) = \frac{1}{C_1}\int_0^t i(t)dt + v_1(0) + \frac{1}{C_2}\int_0^t i(t)dt + v_2(0) + \frac{1}{C_3}\int_0^t i(t)dt + v_3(0)$$

$$= \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)\int_0^t i(t)dt + v_1(0) + v_2(0) + v_3(0)$$

$$\Rightarrow \quad \frac{1}{C_{eq}} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right) \quad \text{and} \quad v(0) = v_1(0) + v_2(0) + v_3(0)$$

Capacitance in Series



$$C_{eq} = \frac{1}{1/C_1 + 1/C_2 + 1/C_3}$$

Capacitances in series are combined like resistances in parallel.

3.3 Physical Characteristics of Capacitors

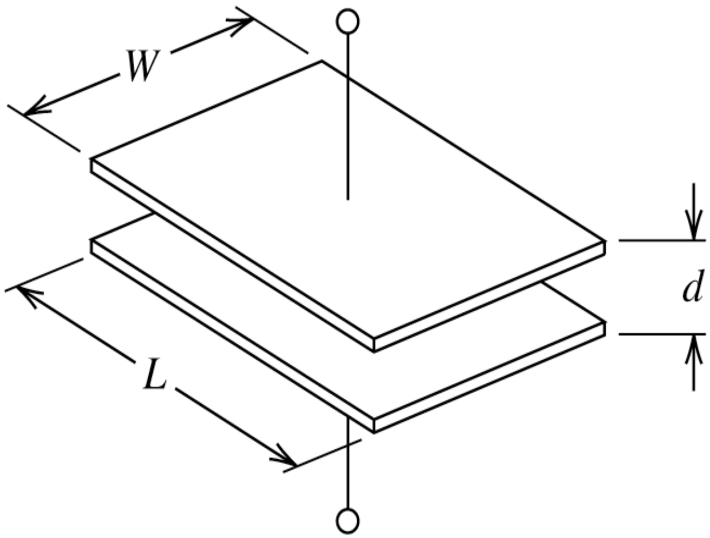


Figure 3.11 A parallel-plate capacitor including dimensions.

$$C = \frac{\in A}{d}$$

$$A = W \times L$$

d 上下極板間的距離

$\in$ 介電常數

真空(vacuum) $\in = \in_0 \cong 8.85 \times 10^{-12}\ F/m$

其他材質 (Table 3.1) $\in = \in_r \in_0$

Example 3.4 A parallel-plate capacitor have rectangular plates 10 cm × 20 cm. Distance is 0.1 mm. Calculate the capacitance.

1. The dielectric is air.
2. The dielectric is mica.

1. The dielectric is air.

$$A = L \times W = \left(10 \times 10^{-2}\right) \times \left(20 \times 10^{-2}\right) = 0.02 m^2$$

$$\in = \in_r \in_0 = 1.00 \times 8.85 \times 10^{-12} \, {}^{F}\!\!\diagup_{m}$$

$$C = \frac{\in A}{d} = \frac{8.85 \times 10^{-12} \times 0.02}{10^{-4}} = 1770 \times 10^{-12} F$$

Example 3.4 A parallel-plate capacitor have rectangular plates 10 cm × 20 cm. Distance is 0.1 mm. Calculate the capacitance.

2. The dielectric is mica.

$$\in_r = 7.0$$

$$C = \frac{\in A}{d} = \frac{\in_r \in_0 A}{d} = \frac{7.0 \times 8.85 \times 10^{-12} \times 0.02}{10^{-4}} = 12{,}390 \times 10^{-12} F$$

Example 3.5

1. Prior to t=0, C_1 is charged to v_1=100V and C_2 has no charge(i.e., v_2=0).
2. At t=0, the switch closes.
3. Compute the total energy stored by C_1 and C_2 before and after the switch closed.

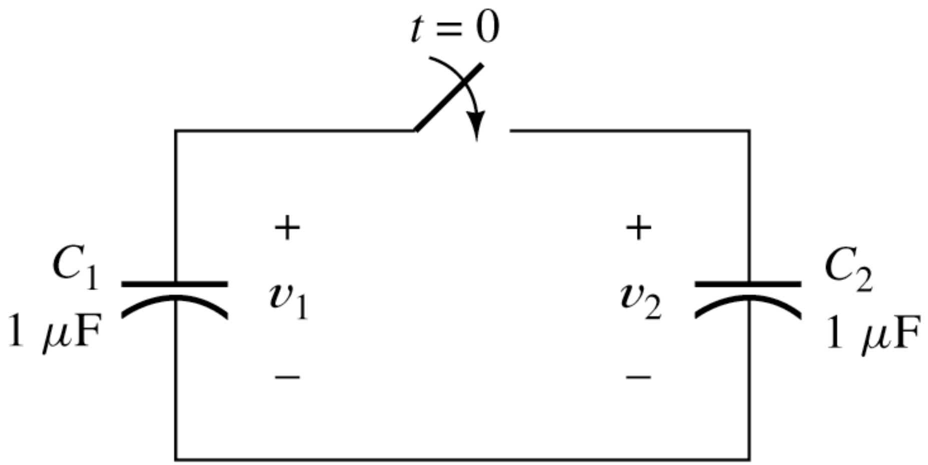


Figure 3.14 See Example 3.5.

Example 3.5

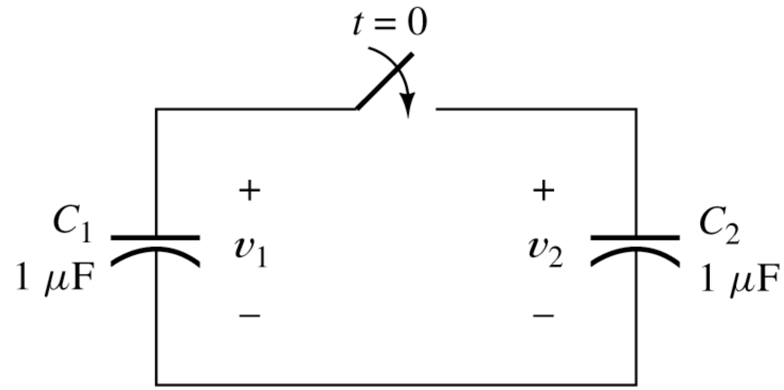


Figure 3.14 See Example 3.5.

1. Before switch closes ($t < 0$)

$$w_1 = \frac{1}{2}C_1 v_1^2 = \frac{1}{2}\left(10^{-6}\right)\left(100\right)^2 = 5mJ$$

$$w_2 = 0$$

$$w_{total} = w_1 + w_2 = 5mJ$$

$$q_1 = C_1 v_1 = 1\times 10^{-6}\times 100 = 100\mu C$$

$$q_2 = 0$$

$$q_{eq} = q_1 + q_2 = 100\mu C$$

Example 3.5

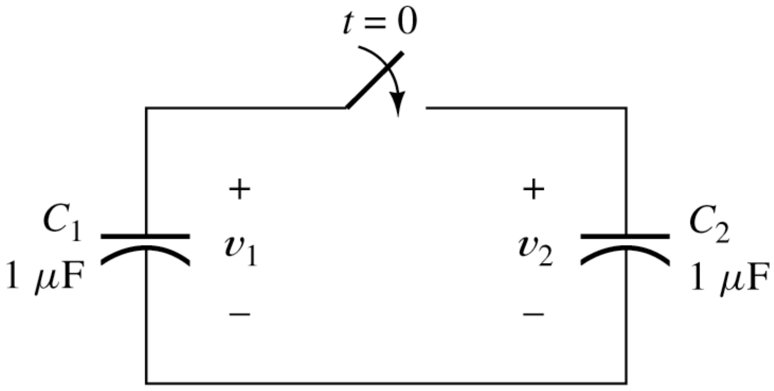


Figure 3.14 See Example 3.5.

2. After switch closes (t >= 0)

C_1, C_2, 並聯

$$\Rightarrow \quad C_{eq} = C_1 + C_2 = 2\mu F$$

等效電容兩端電壓

$$v_{eq} = \frac{q_{eq}}{C_{eq}} = \frac{100\mu C}{2\mu F} = 50V$$ (假設儲存於兩電容之總電荷數不變)

$$v_1 = v_2 = v_{eq}$$

Example 3.5

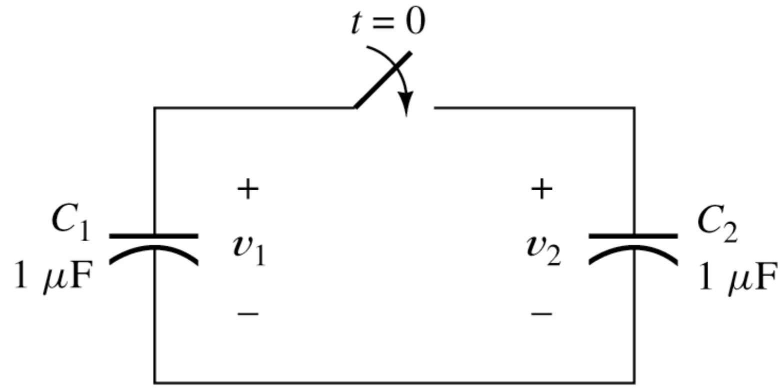


Figure 3.14 See Example 3.5.

儲存與兩電容之能量

$$w_1 = \frac{1}{2}C_1 v_{eq}^2 = \frac{1}{2}\left(10^{-6}\right)(50)^2 = 1.25mJ$$

$$w_2 = \frac{1}{2}C_2 v_{eq}^2 = \frac{1}{2}\left(10^{-6}\right)(50)^2 = 1.25mJ$$

$$\Rightarrow \quad w_{total} = w_1 + w_2 = 2.5mJ$$

儲存於兩電容之總能量為switch closes 前之一半

⇒ Parasitic resistances or parasitic inductance (寄生電阻消耗或寄生電感儲存能量)

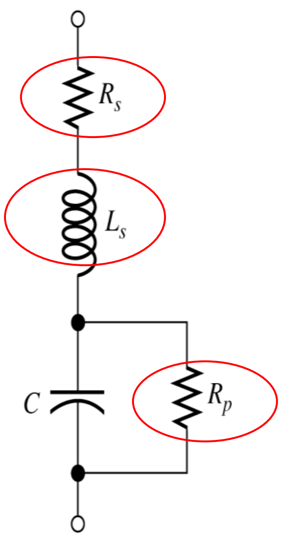
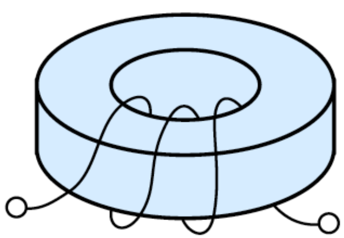


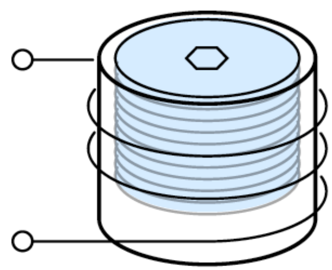
Figure 3.13 The circuit model for a capacitor including the parasitic elements R_s, L_s, and R_p.

3.4 Inductance 電感

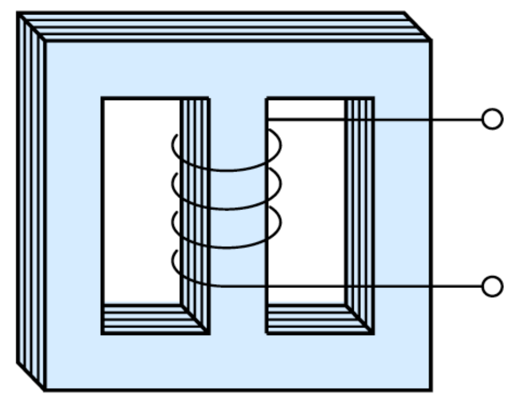
- 電感為線圈(coil)形式之導線圍繞磁性核心的電路元件。
- 電流流過線圈會產生磁場(magnetic field)或磁通量(magnetic flux)。



(a) Toriodal inductor



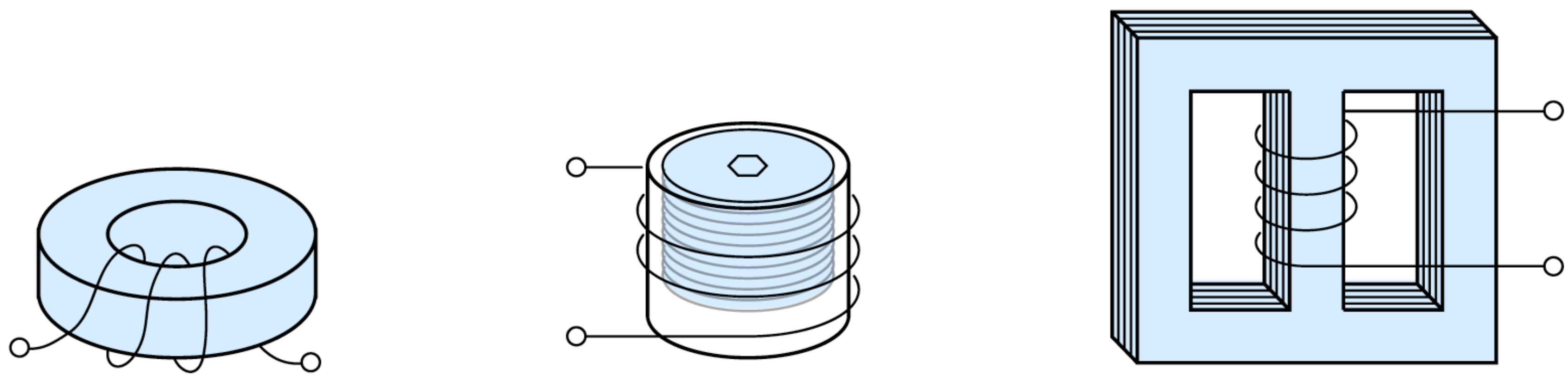
(b) Coil with an iron-oxide slug that can be screwed in or out to adjust the inductance



(c) Inductor with a laminated iron core

Figure 3.15 An inductor is constructed by coiling a wire around some type of form.

- 電流改變會產生磁場改變(Faraday's law) ，而磁場改變會產生一個電壓(感應電動勢)在線圈兩端，而此電壓值正比於產生磁場的電流改變率。



(a) Toriodal inductor

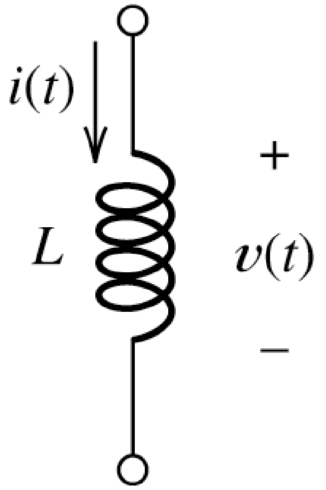
(b) Coil with an iron-oxide slug that can be screwed in or out to adjust the inductance

(c) Inductor with a laminated iron core

Figure 3.15 An inductor is constructed by coiling a wire around some type of form.

V-I Relationship

- 理想電感兩端電壓與電流對時間微分成正比。
- 常數L為電感值(inductance)，單位為亨利(H, henries)，等於volt seconds/ampere (V •Sec/A) 。
- 一般電感值在數個micro H(1uH= 10^{-6})到數十H之間。
- 通過電感的電流參考方向為電感兩端電壓降落的方向(由正極流入，負極流出)，具 passive configuration特性。

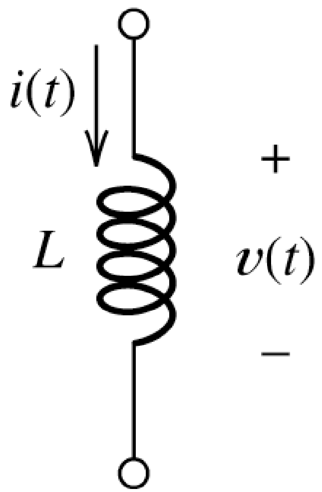


$$v(t) = L\frac{di}{dt}$$

Current in Terms of Voltage

$$v(t) = L\frac{di}{dt}$$

$$di = \frac{1}{L}v(t)dt$$

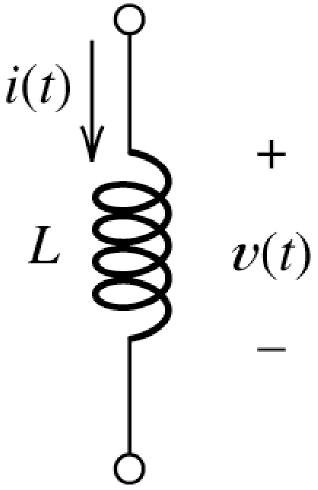


$$v(t) = L\frac{di}{dt}$$

$$\int_{i(t_0)}^{i(t)} di = \frac{1}{L}\int_{t_0}^{t} v(t)dt$$

$$i(t) = \frac{1}{L}\int_{t_0}^{t} v(t)dt + i(t_0)$$

Stored Energy



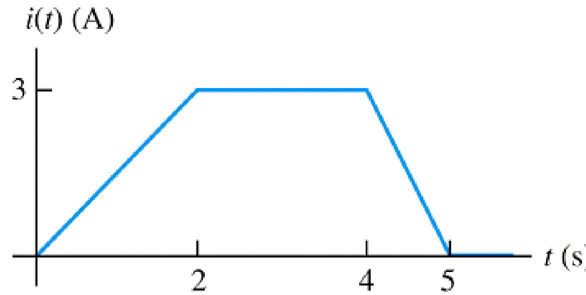
$$v(t) = L\frac{di}{dt}$$

$$p(t) = v(t)i(t)$$
$$= Li(t)\frac{di}{dt}$$

$$w(t) = \int_{t_0}^{t} p(t)dt$$
$$= \int_{t_0}^{t} Li(t)\frac{di}{dt}dt$$
$$= \int_{0}^{i(t)} Lidi \quad \text{(Assume } i(t_0)\text{=0)}$$
$$= \frac{1}{2}Li^2(t)$$

Example 3.6 Voltage, Power, and Energy for an Inductance

L=5 H, $i(t)$ is given. Plot voltage, the power delivered and energy stored for t = 0~5 s.



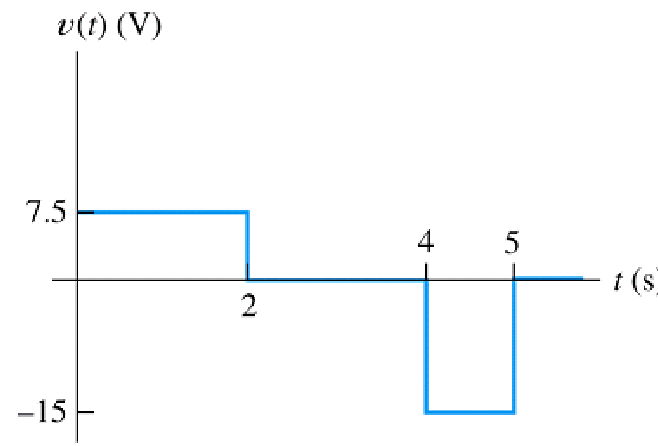
1. Express $i(t)$ as a function of time

$$i(t)=\begin{cases} 1.5tA & for \quad 0<t<2 \\ 3A & for \quad 2<t<4 \\ 3(5-t)A & for \quad 4<t<5 \end{cases}$$

2. Calculate $v(t)$

$$v(t)=L\frac{di}{dt}$$

$$v(t)=\begin{cases} 7.5V & for \quad 0<t<2 \\ 0V & for \quad 2<t<4 \\ -15V & for \quad 4<t<5 \end{cases}$$

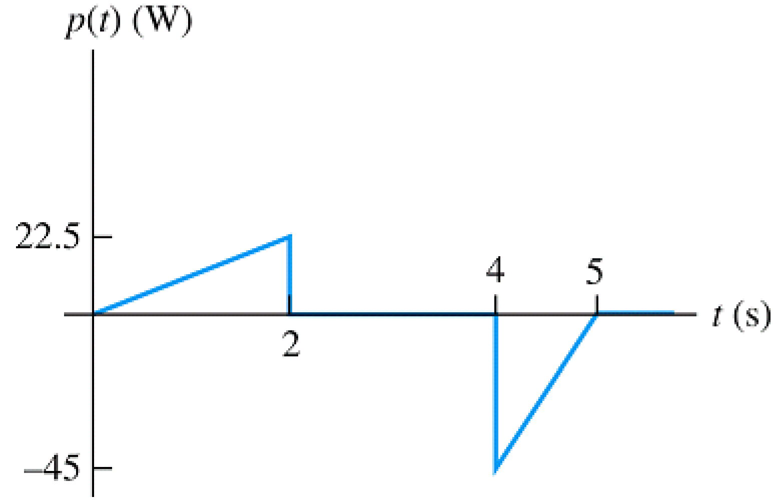


Example 3.6 Voltage, Power, and Energy for a Inductance

3. $p(t)$

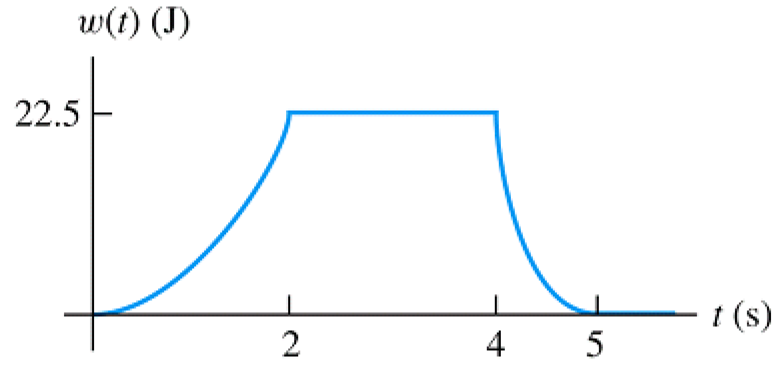
$$p(t) = v(t)i(t)$$

$$p(t) = \begin{cases} 11.25tW & for \quad 0 < t < 2 \\ 0W & for \quad 2 < t < 4 \\ -45(5-t)W & for \quad 4 < t < 5 \end{cases}$$



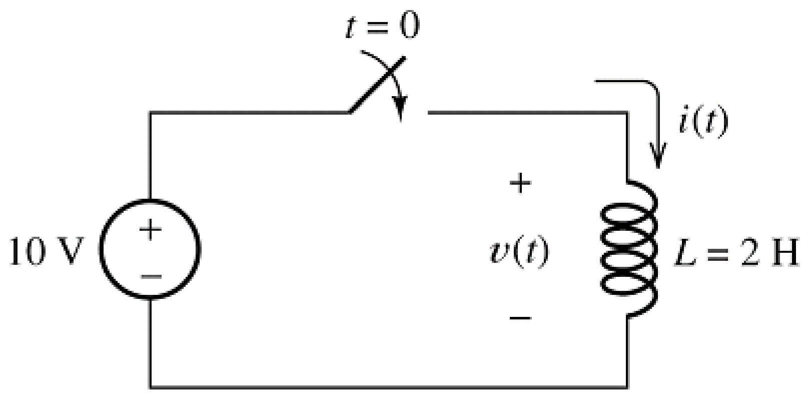
4. Energy

$$w(t) = \frac{1}{2}Li^2(t)$$



Example 3.7 Inductor Current with Constant Applied Voltage

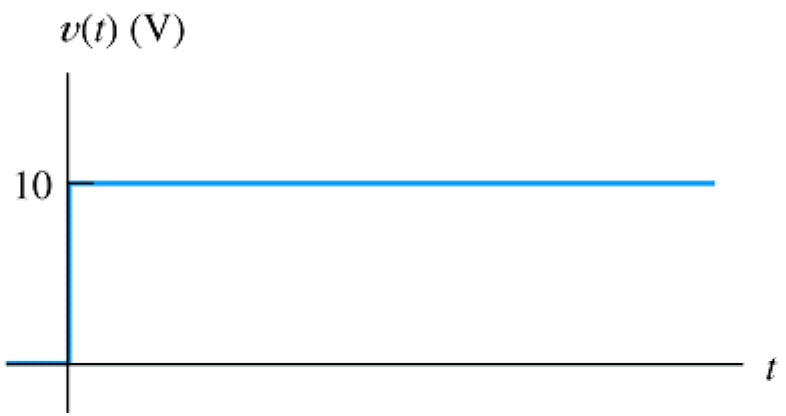
Switch closes at t=0, connecting a 10-V source to a 2-H inductance. Find $i(t)$.



$$v(t) = L\frac{di}{dt}$$

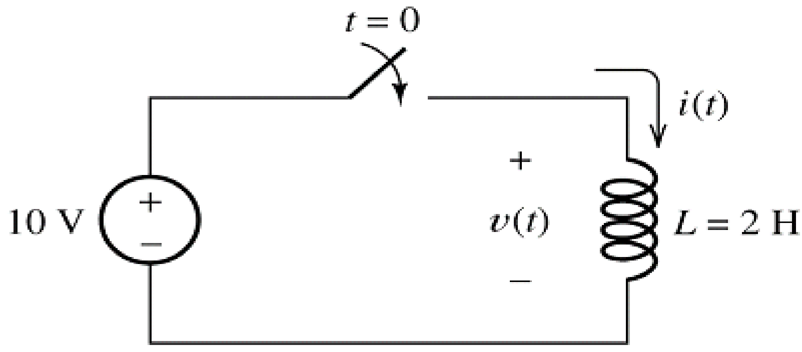
剛導通時$i(t)$=0.

1. V(t)



Example 3.7 Inductor Current with Constant Applied Voltage

Switch closes at t=0, connecting a 10-V source to a 2-H inductance. Find $i(t)$.

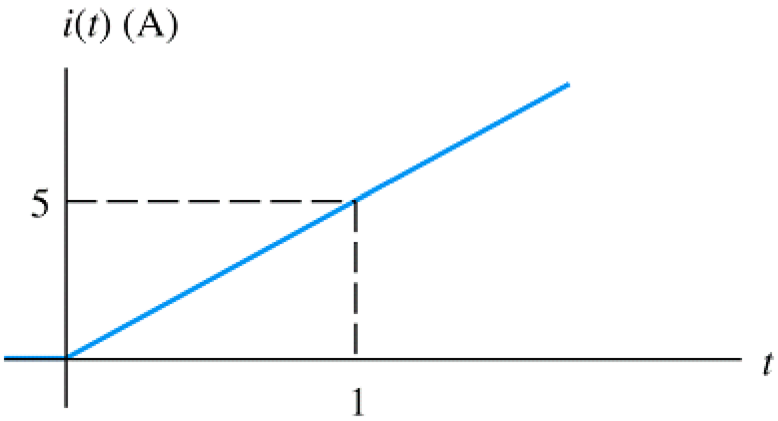


2. $i(t)$ t>0

$$i(t) = \frac{1}{L}\int_{t_0}^{t} v(t)dt + i(t_0)$$

$$= \frac{1}{2}\int_{0}^{t} 10dt$$

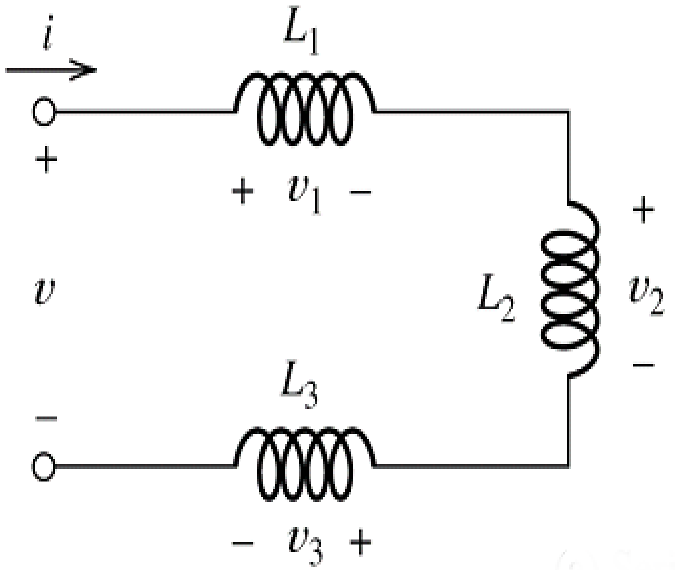
$$= 5tA \quad for \quad t > 0$$



If we open the circuit at t=1, since $v(t) = L\frac{di}{dt}$ we got a large voltage.

➡ 開關含有電感的電路會產生大電壓。

3.5 Inductance in Series and Parallel



KVL

$$v(t) = v_1(t) + v_2(t) + v_3(t)$$

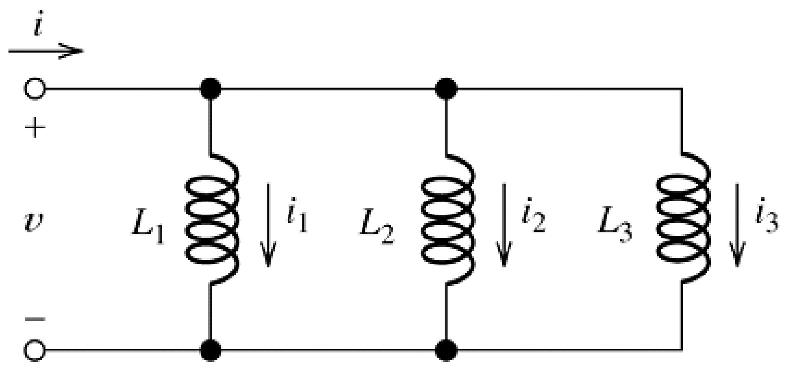
$$v(t) = L\frac{di}{dt}$$

$$v(t) = L_1\frac{di(t)}{dt} + L_2\frac{di(t)}{dt} + L_3\frac{di(t)}{dt}$$

$$= (L_1 + L_2 + L_3)\frac{di(t)}{dt} = L_{eq}\frac{di(t)}{dt}$$

$$L_{eq} = L_1 + L_2 + L_3$$

Inductance in Parallel



KCL

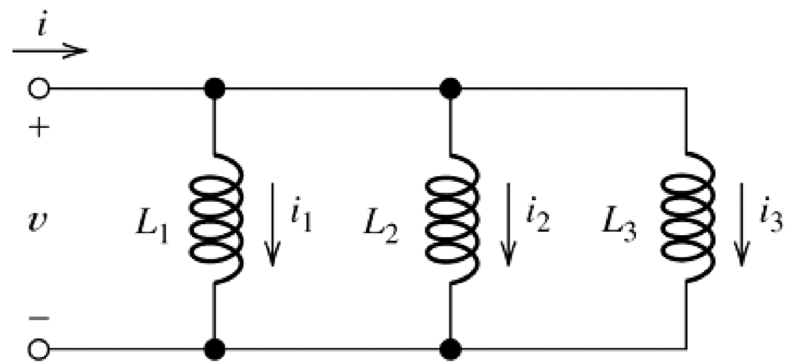
$$i(t) = i_1(t) + i_2(t) + i_3(t)$$

$$i(t) = \frac{1}{L}\int_{t_0}^{t} v(t)dt + i(t_0)$$

$$\Rightarrow \quad i(t) = \frac{1}{L_1}\int_0^t v(t)dt + i_1(0) + \frac{1}{L_2}\int_0^t v(t)dt + i_2(0) + \frac{1}{L_3}\int_0^t v(t)dt + i_3(0)$$

$$= \left(\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}\right)\int_0^t v(t)dt + i_1(0) + i_2(0) + i_3(0)$$

Inductance in Parallel



$$i(t) = \frac{1}{L_{eq}} \int_0^t v(t)dt + i(0)$$

$$\frac{1}{L_{eq}} = \left(\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} \right) \quad \text{and} \quad i(0) = i_1(0) + i_2(0) + i_3(0)$$

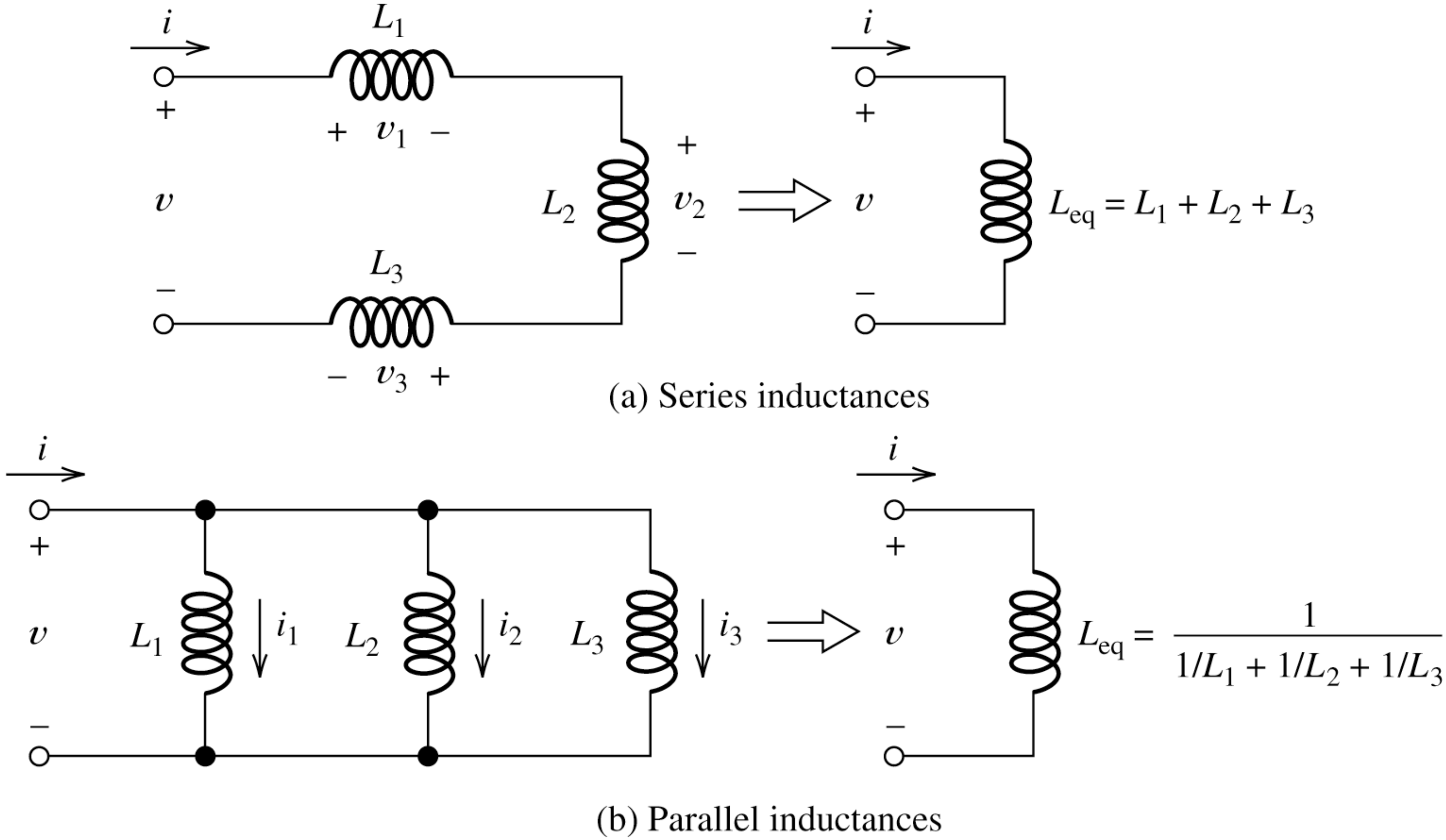
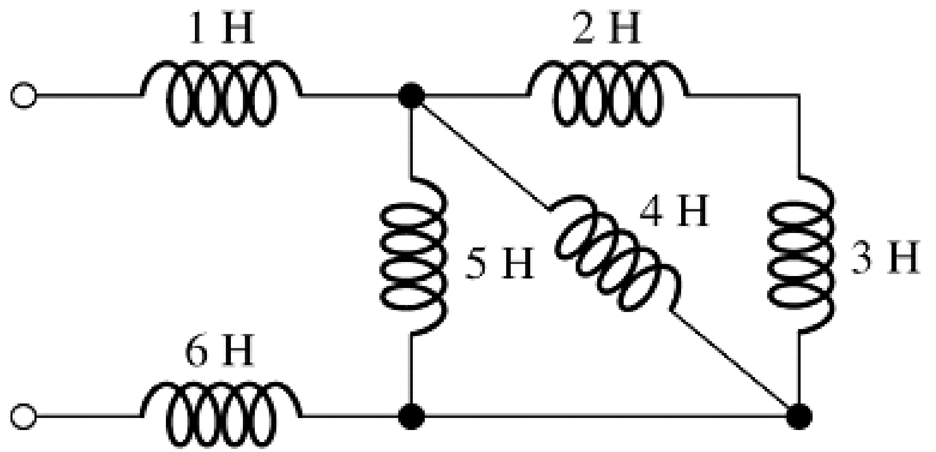


Figure 3.20 Inductances in series and parallel are combined in the same manner as resistances.

Exercise 3.10



- The 2-H and 3-H are in series ⇒ 5 H.
- The equivalent 5H is in parallel with the 5-H and 4-H ⇒ $1/(1/5 + 1/4 + 1/5) = 1.538$ H.
- The equivalent 1.538 H is in series with the 1-H and 6-H ⇒ $1.538 + 1 + 6 = 8.538$ H.

3.6 Practical Inductors

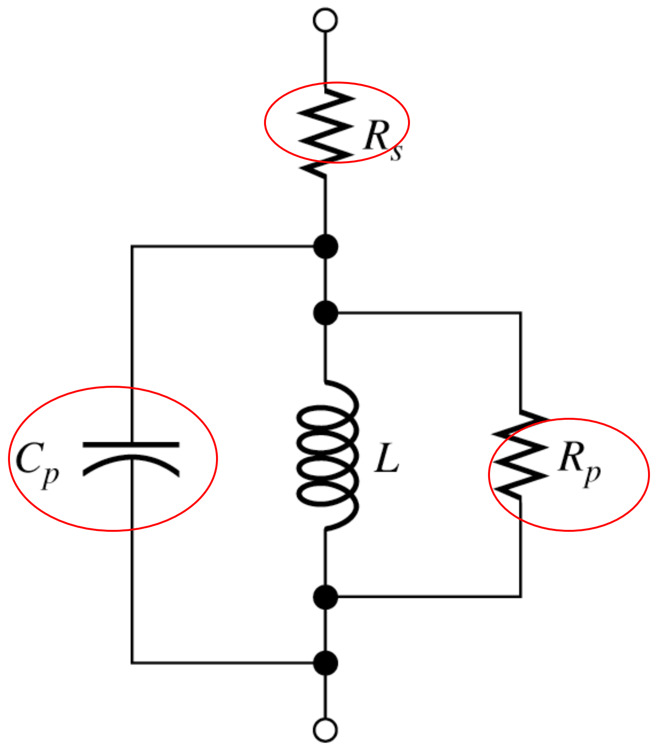
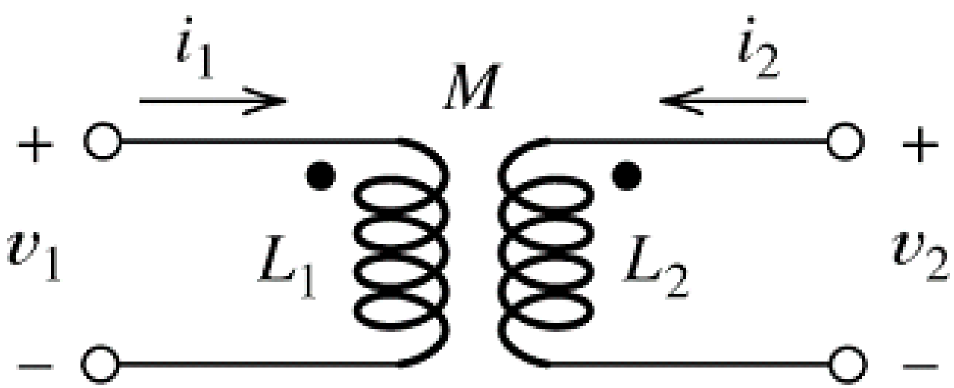


Figure 3.22 Circuit model for real inductors including several parasitic elements.

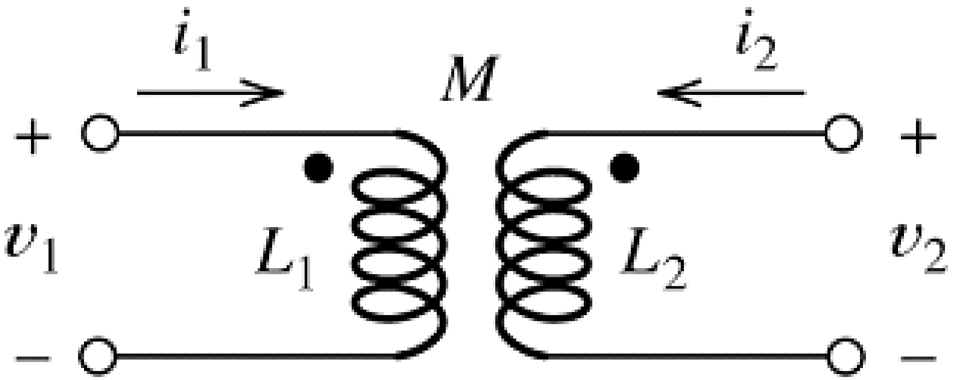
3.7 Mutual Inductance (互感)

- 若數個線圈圍繞相同的磁性核心，則不同線圈通過電流所引發的磁通量會彼此影響。
- 自感(self inductance) L_1 & L_2表示自身的電感效應，互感(mutual inductance) M 表示彼此相互影響所產生的電感效應。



•不同線圈電感效應產生的磁力線方向可能相同(增加)或相反(減弱)。

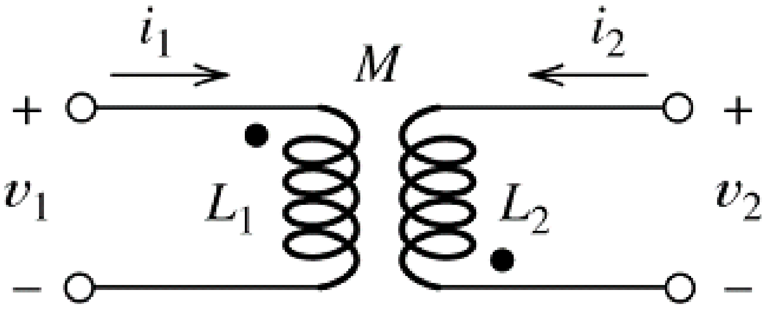
•以兩端黑點為參考方向，兩線圈電流皆流入或流出黑點則電感效應增強。



$$v_1 = L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}$$

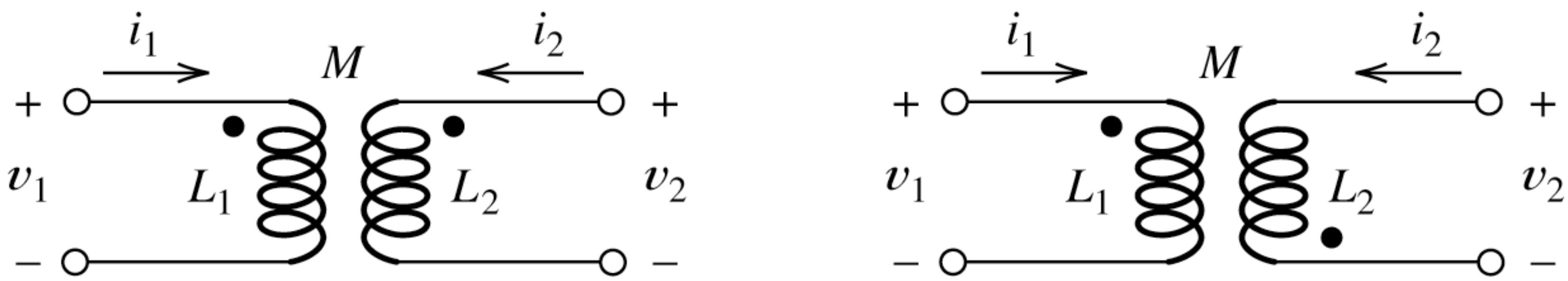
$$v_2 = M \frac{di_1}{dt} + L_2 \frac{di_2}{dt}$$

- 兩線圈電流一流入，一流出黑點則電感效應減弱。



$$v_1 = L_1 \frac{di_1}{dt} - M \frac{di_2}{dt}$$

$$v_2 = -M \frac{di_1}{dt} + L_2 \frac{di_2}{dt}$$



$$v_1 = L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}$$

$$v_2 = M \frac{di_1}{dt} + L_2 \frac{di_2}{dt}$$

(a)

$$v_1 = L_1 \frac{di_1}{dt} - M \frac{di_2}{dt}$$

$$v_2 = -M \frac{di_1}{dt} + L_2 \frac{di_2}{dt}$$

(b)

Figure 3.23 Circuit symbols and $v - i$ relationships for mutually coupled inductances.

電容與電感的相對關係

電容	電感
$i(t) = C\dfrac{dv(t)}{dt}$	$v(t) = L\dfrac{di(t)}{dt}$
$v(t) = \dfrac{1}{C}\displaystyle\int_{t_0}^{t} i(x)\,dx + v(t_0)$	$i(t) = \dfrac{1}{L}\displaystyle\int_{t_0}^{t} v(x)\,dx + i(t_0)$
$p(t) = Cv(t)\dfrac{dv(t)}{dt}$	$p(t) = Li(t)\dfrac{di(t)}{dt}$
$w(t) = \frac{1}{2}Cv(t)^2$	$w(t) = \frac{1}{2}Li^2(t)$

電容串聯	$\frac{1}{C_s}=\frac{1}{C_1}+\frac{1}{C_2}+\cdots\cdots+\frac{1}{C_N}$	類似電阻並聯
電容並聯	$C_p=C_1+C_2+\cdots\cdots+C_N$	類似電阻串聯
電感串聯	$L_s=L_1+L_2+\cdots\cdots+L_N$	類似電阻串聯
電感並聯	$\frac{1}{L_p}=\frac{1}{L_1}+\frac{1}{L_2}+\cdots\cdots+\frac{1}{L_N}$	類似電阻並聯