Schedule…

Date	Day	Class No.	Title	Chapters	HW Due date	Lab Due date	Exam
6 Oct	Mon	10	Energy Storage	3.7, 4.1		NO LAB	
7 Oct	Tue					NO LAB	
8 Oct	Wed	11	Dynamic Circuits	4.2 – 4.4			
9 Oct	Thu						
10 Oct	Fri		Recitation		HW 4		
11 Oct	Sat						
12 Oct	Sun						
13 Oct	Mon	12	Exam 1 Review			LAB 4	EXAM 1
14 Oct	Tue						

Energy

Moro. 7: 48

48 Wherefore, my beloved brethren, pray unto the Father with all the **energy** of heart, that ye may be filled with this love, which he hath bestowed upon all who are true followers of his Son, Jesus Christ; that ye may become the sons of God; that when he shall appear we shall be like him, for we shall see him as he is; that we may have this hope; that we may be purified even as he is pure. Amen.

Lecture 10 – Energy Storage

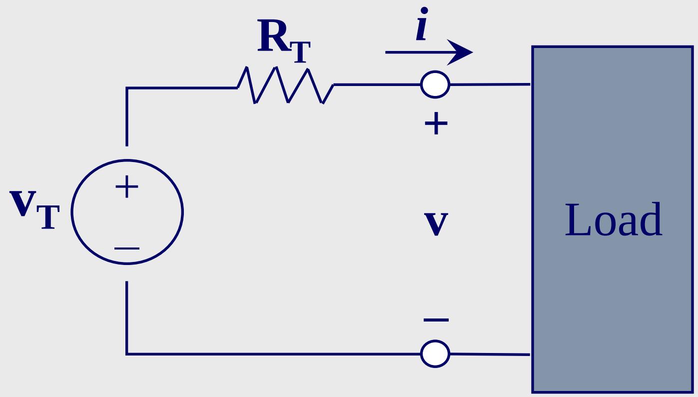
Maximum Power Transfer

Capacitors

Inductors

Maximum Power Transfer

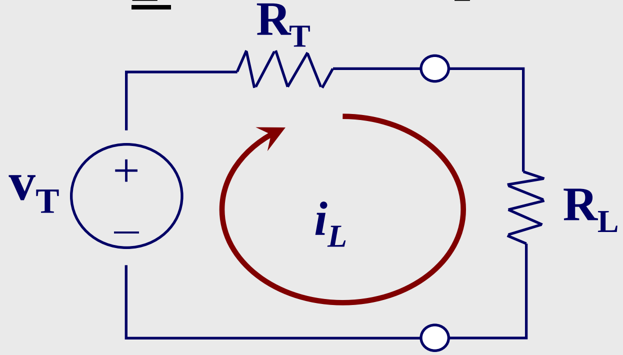
- Equivalent circuit representations are important in power transfer analysis



- **Ideally** all power from source is absorbed by the load
  - But some power will be absorbed by internal circuits (represented by $\mathbf{R_T}$)

Maximum Power Transfer

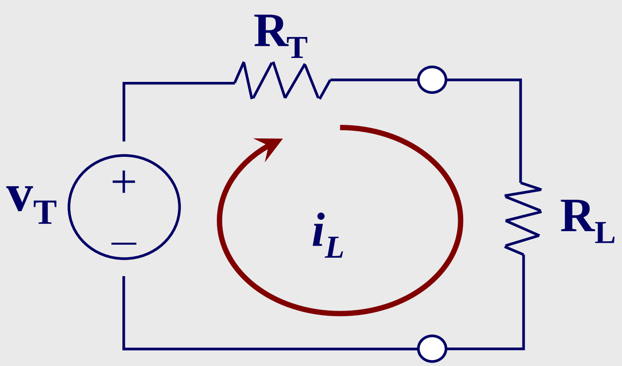
- Efficiently transferring power from source to load means that internal resistances (**R_T**) must be minimized
  - i.e. for a given **R_L** we want **R_T** as small as possible!



- For a given **R_T** there is a specific **R_L** that will maximize power transfer to the load

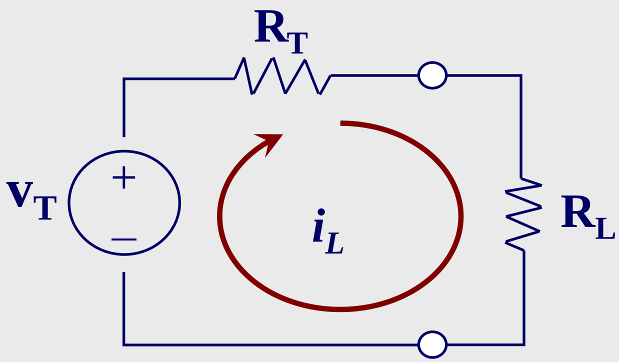
Maximum Power Transfer

- Consider the power (**P_L**) absorbed by the load



Maximum Power Transfer

- Consider the power (**P_L**) absorbed by the load



$$P_L = i_L^{\,2} R_L$$

BUT

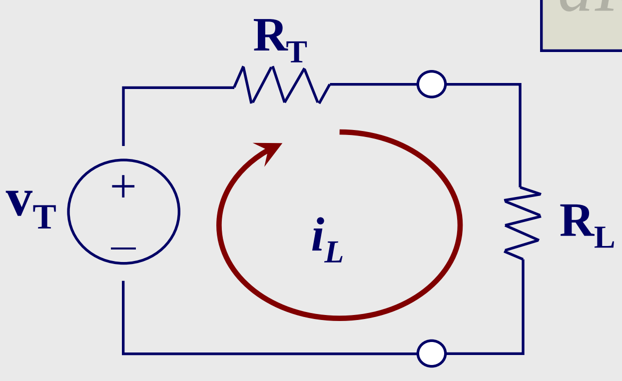
$$i_L = \frac{v_T}{R_L + R_T}$$

Therefore

$$P_L = \frac{v_T^{\,2}}{(R_L + R_T)^2} R_L$$

Maximum Power Transfer

- The **maximum** power transfer can be found by calculating $d\mathbf{P_L}/d\mathbf{R_L} = 0$



$$\frac{dP_L}{dR_L} = \frac{v_T^{\,2}\left(R_L + R_T\right)^2 - 2v_T^{\,2}R_L\left(R_L + R_T\right)}{\left(R_L + R_T\right)^4} = 0$$

OR

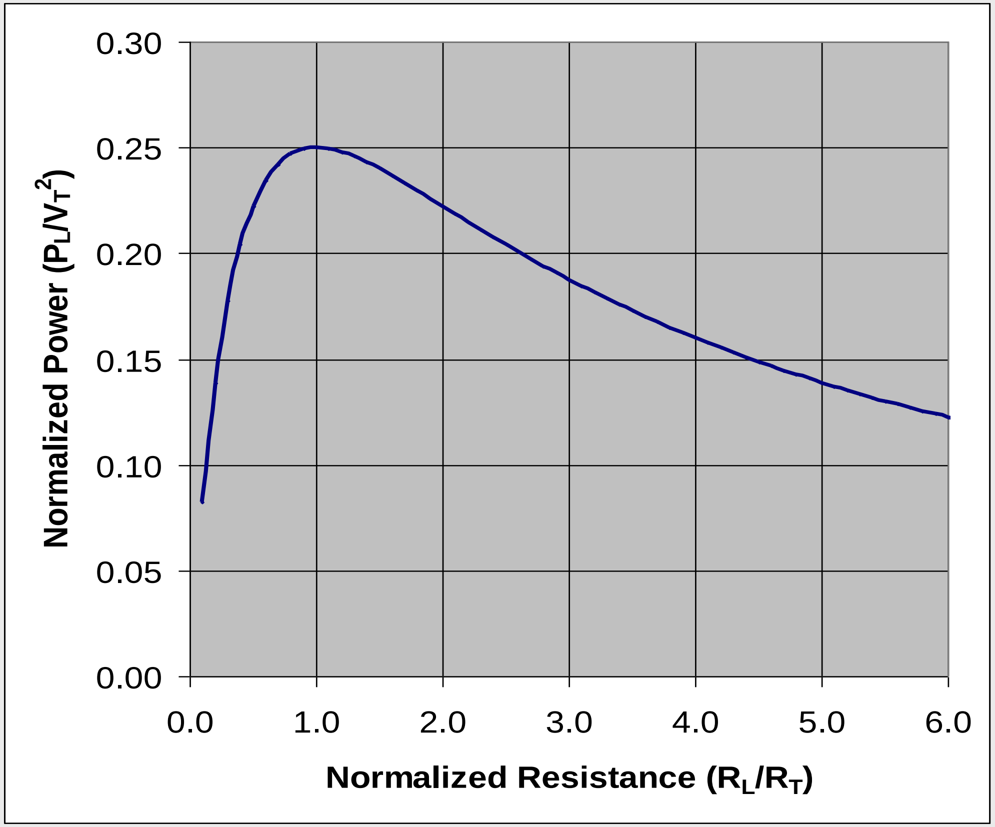
$$\left(R_L + R_T\right)^2 - 2R_L\left(R_L + R_T\right) = 0$$

OR

$$R_L = R_T$$

NB: assumes $\mathbf{R_T}$ is fixed and $\mathbf{R_L}$ is variable

Maximum Power Transfer



<u>When $\mathbf{R_L < R_T}$:</u>

P_L is lowered since **v_L** goes down

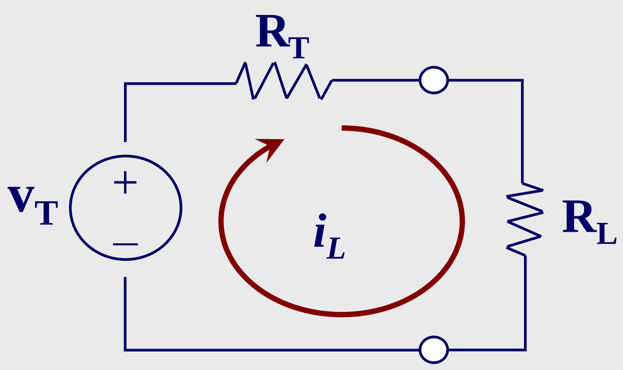
<u>When $\mathbf{R_L > R_T}$:</u>

P_L is lowered since less current (***i_L***) flows

To transfer maximum power to the load, the source and load resistors must be **matched** (i.e. **$R_T = R_L$**). Power is attenuated as **R_L** departs from **R_T**

Maximum Power Transfer

<u>Maximum power theorem</u>: maximum power is delivered by a source (represented by its Thévenin equivalent circuit) is attained when the load (**R_L**) is equal to the Thévenin resistance **R_T**



$$P_L = \frac{v_T^2}{\left(R_L + R_T\right)^2} R_L$$

$$P_{LMax} = \frac{v_T^2}{4R_L}$$

$$= \frac{R_L i_T^2}{4}$$

NB: Substitute (**R_T** = **R_L**) to get **P_{LMax}**

Maximum Power Transfer

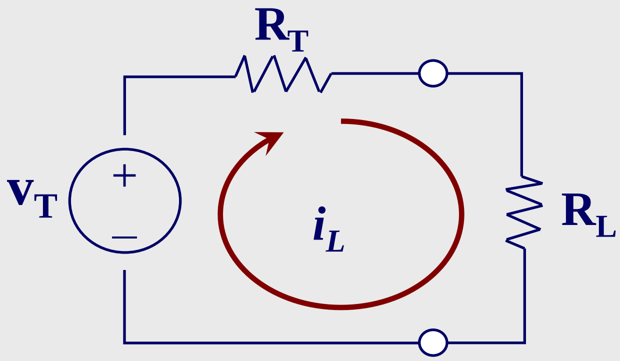
Efficiency of power transfer (η): the ratio of the power delivered to the load (**P_{out}**), to the power supplied by the source (**P_{in}**)

$$\eta = \frac{p_{out}}{p_{in}}$$

NB: $P_{out} = P_L$

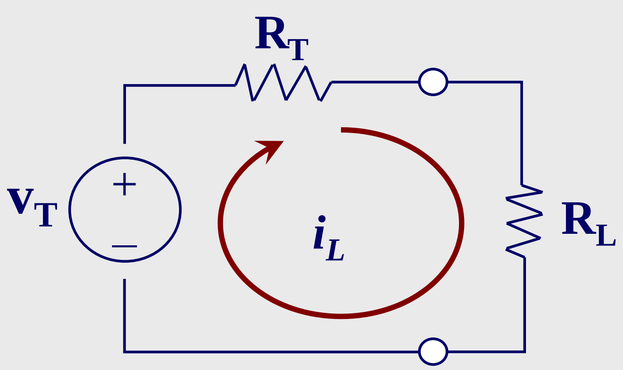
Maximum Power Transfer

Efficiency of power transfer (η): the ratio of the power delivered to the load (**P_{out}**), to the power supplied by the source (**P_{in}**)



Maximum Power Transfer

Efficiency of power transfer (η): the ratio of the power delivered to the load (P_{out}), to the power supplied by the source (P_{in})



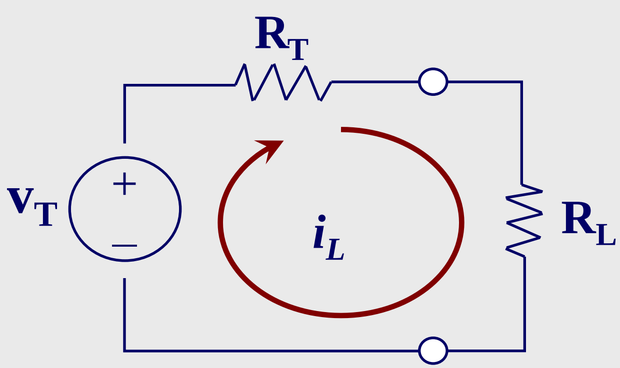
$$P_{in} = i_L v_T = v_T\left(\frac{v_T}{R_T + R_L}\right)$$

$$P_{inMax} = \frac{v_T^{\,2}}{2R_L} = \frac{R_L i_T^{\,2}}{2}$$

NB: Substitute (R_T = R_L) to get P_{inMax}

Maximum Power Transfer

<u>Efficiency of power transfer (η)</u>: the ratio of the power delivered to the load (**P_{out}**), to the power supplied by the source (**P_{in}**)

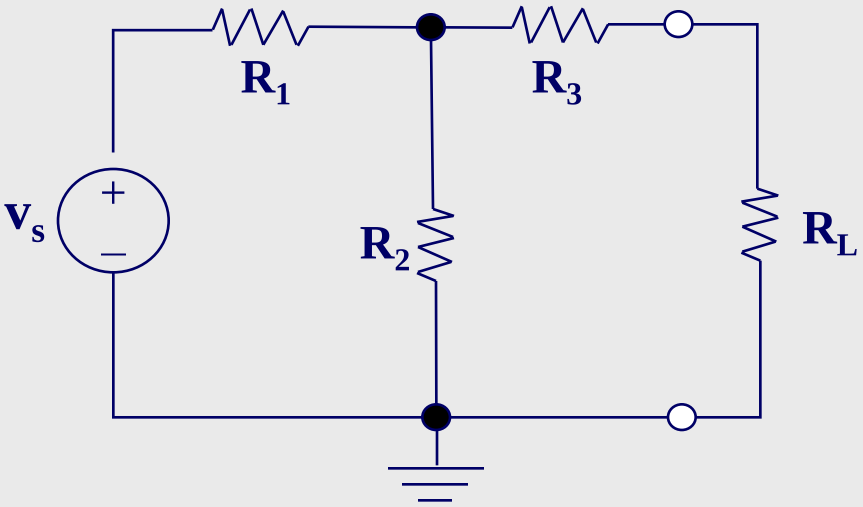


$$\eta_{\max} = \frac{P_{outMax}}{P_{inMax}} = \frac{v_T^2}{4R_L} \cdot \frac{2R_L}{v_T^2} = \frac{1}{2}$$

In other words, **at best**, only 50% efficiency can be achieved

Maximum Power Transfer

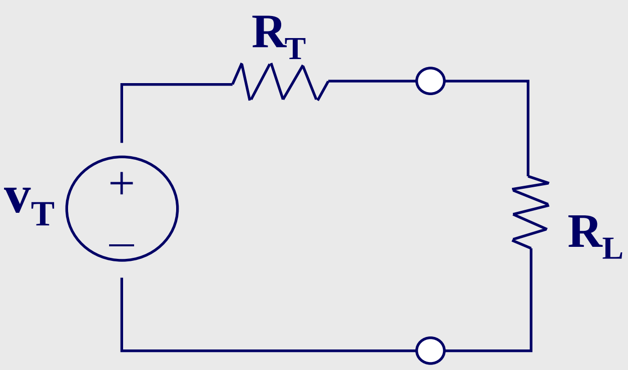
- **<u>Example1</u>**: Find the maximum power delivered to $\mathbf{R_L}$
  - v_s = 18V, $\mathbf{R_1}$ = 3Ω, $\mathbf{R_2}$ = 6Ω, $\mathbf{R_3}$ = 2Ω



Maximum Power Transfer

- **<u>Example1</u>**: Find the maximum power delivered to $\mathbf{R_L}$
  - $v_s = 18V$, $\mathbf{R_1} = 3\Omega$, $\mathbf{R_2} = 6\Omega$, $\mathbf{R_3} = 2\Omega$

1. Find Thévenin equivalent circuit

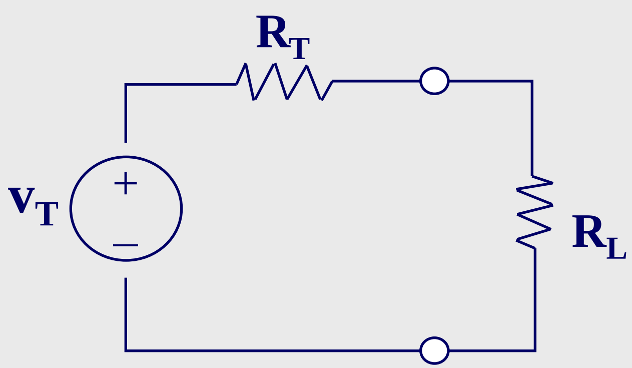


$$v_T = \frac{R_2}{R_1 + R_2} v_s = 12V$$

$$R_T = R_3 + R_1 \| R_2 = 4\Omega$$

Maximum Power Transfer

- **Example1**: Find the maximum power delivered to $\mathbf{R_L}$
  - v_s = 18V, $\mathbf{R_1}$ = 3Ω, $\mathbf{R_2}$ = 6Ω, $\mathbf{R_3}$ = 2Ω



1. Find Thévenin equivalent circuit
2. Set $\mathbf{R_L} = \mathbf{R_T}$
3. Calculate $\mathbf{P_{LMax}}$

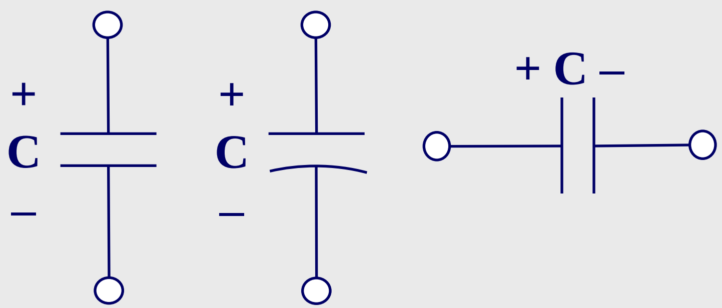
$$P_{L\max} = 0.5 P_{in\max} = 0.5\frac{v_T^2}{2R_L} = 0.5\frac{(12)^2}{8} = 9W$$

Dynamic Energy Storage Elements

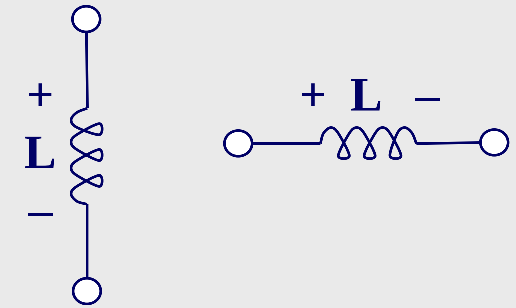
Capacitor and Inductor

Storage Elements

- To this point, circuits have consisted of either:
  - **DC Sources** (active element, provide energy)
  - **Resistors** (passive element, absorb energy)
- Some passive (non-source) elements can store energy
  - **Capacitors** – store voltage
  - **Inductors** – store current



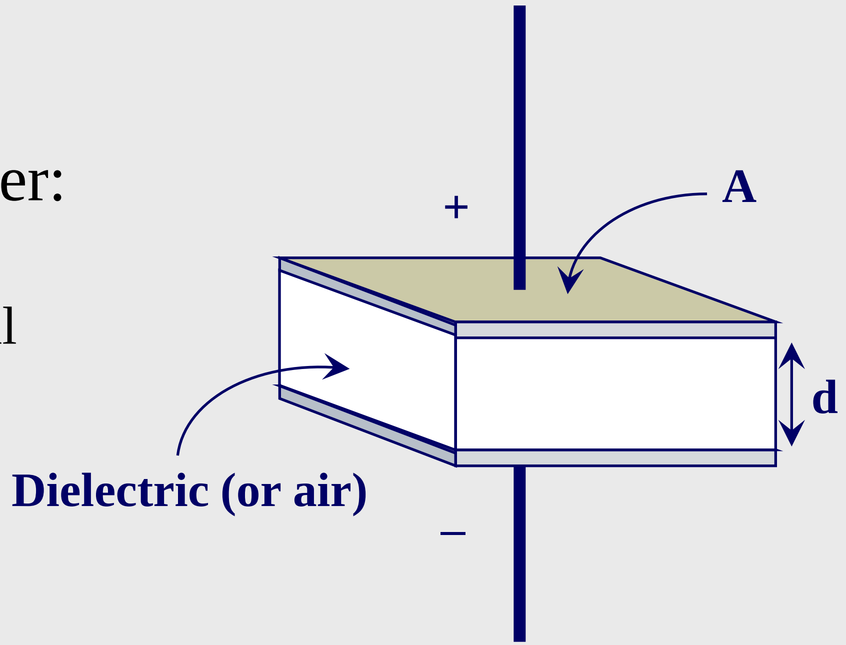
Capacitor symbols



Inductor symbols

Ideal Capacitor

- A capacitor (**C**) is composed of:
  - 2 parallel conducting plates
    - cross-sectional area **A**
  - Separated distance **d** by either:
    - Air
    - Dielectric (insulating) material



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

C – Capacitance

ε – relative permittivity (dielectric constant)

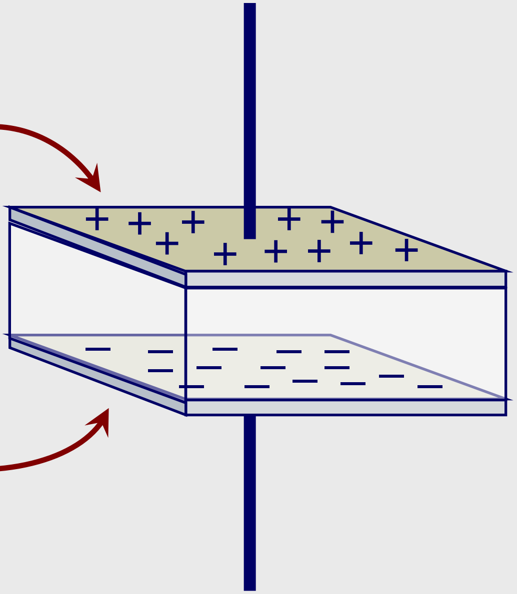
NB: the parallel plates **do not touch** – thus under DC current a capacitor acts like an **open circuit**

Ideal Capacitor

<u>Capacitance</u>: a measure of the ability to store energy in the form of separated charge (or an electric field)

$$q = Cv$$

The charge **q+** on one plate is equal to the charge **q–** on the other plate



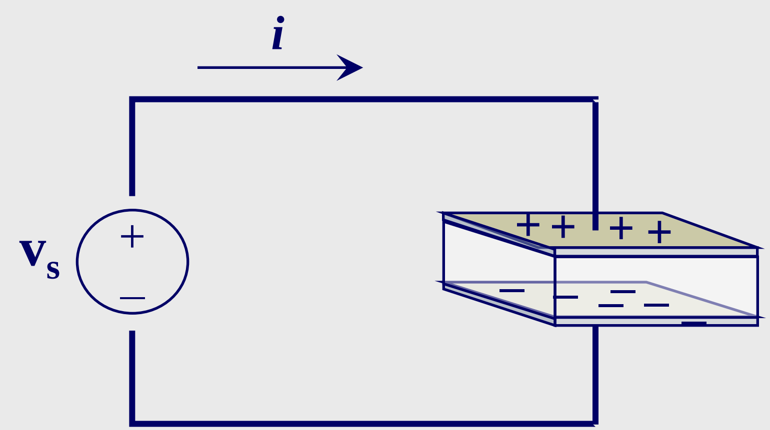
<u>Farad (*F*)</u>: unit of capacitance.
1 farad = 1 coulomb/volt (C/V)

Ideal Capacitor

- **No current** can flow through a capacitor if the voltage across it is **constant** (i.e. connected to a **DC source**)
- **BUT** when a DC source is applied to a capacitor, there is an **initial** circuit current as the capacitor plates are charged ('**charging**' the capacitor)

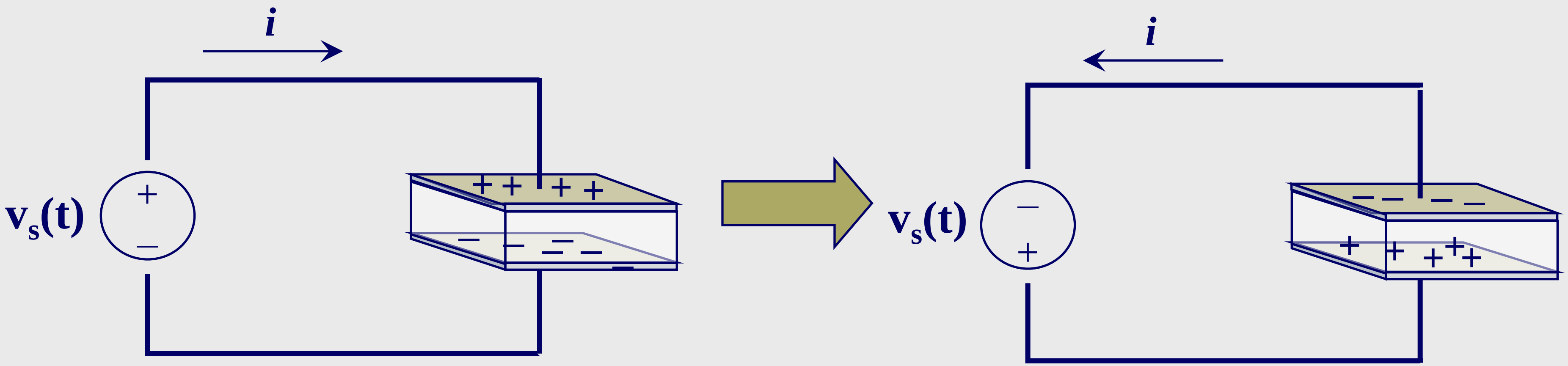
$$i(t) = \frac{dq(t)}{dt}$$

<u>Charging the capacitor</u>: a current flows as electrons leave one plate to accumulate on the other.
This occurs until the voltage across the capacitor = source voltage



Ideal Capacitor

- **Capacitor with an AC source**: since AC sources periodically reverse voltage directions, the capacitor plates will change charge polarity accordingly
  - With each polarity change, the capacitor goes through a '**charging**' state, thus current continuously flows
  - Just as with a DC source, **no electrons cross between the plates**
  - Just as with a DC source, **voltage across a capacitor cannot change instantaneously**



Ideal Capacitor

- i – v characteristic for an ideal capacitor

Differentiate both sides

$$q(t) = Cv(t) \quad \Rightarrow \quad \frac{dq(t)}{dt} = \frac{dCv(t)}{dt}$$

BUT

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

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

OR

$$v(t) = \frac{1}{C}\int_{-\infty}^{t} i_C(\tau)d\tau$$

Ideal Capacitor

- i – v characteristic for an ideal capacitor

$$v(t) = \frac{1}{C}\int_{-\infty}^{t} i_C(\tau)d\tau$$

NB: Assumes we know the value of the capacitor from time (**τ = -∞**) until time (**τ** = t)

Instead

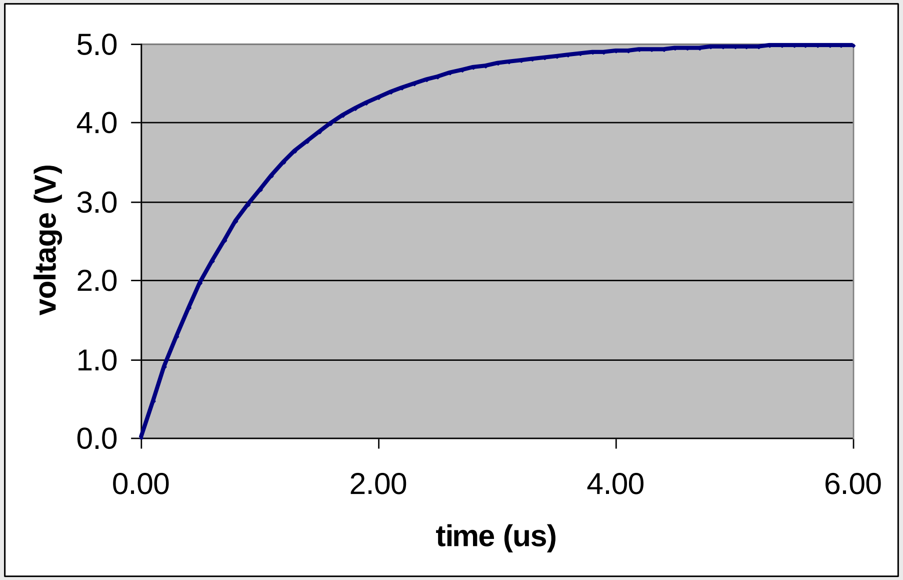
$$v(t) = \frac{1}{C}\int_{t_0}^{t} i_C(\tau)d\tau + v(t_0)$$

Initial time (often $\mathbf{t_0}$ = 0)

Initial condition

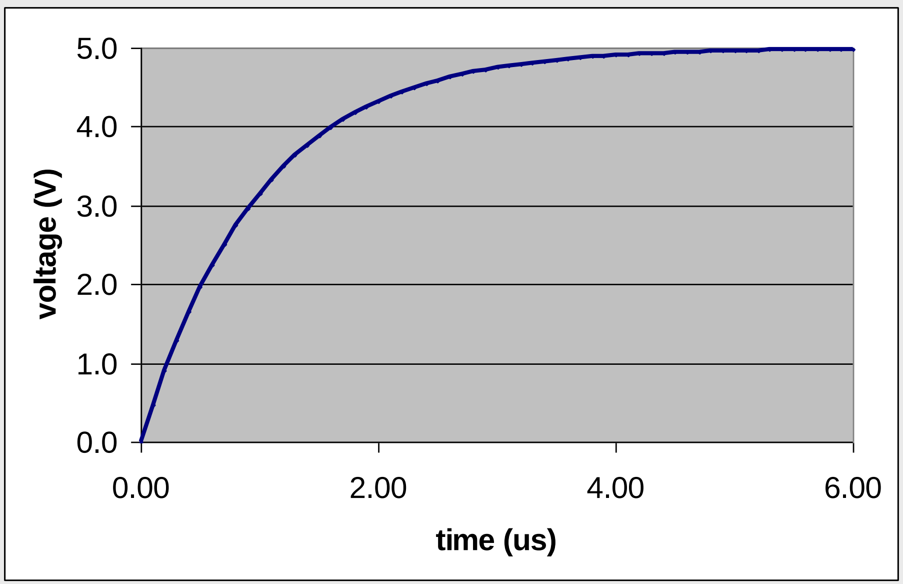
Ideal Capacitor

- **<u>Example2</u>**: calculate the current through the capacitor $C = 0.1\mu F$ with the voltage as shown: $\mathbf{v(t) = 5(1-e^{-t/10^{-6}})}$



Ideal Capacitor

- **Example2**: calculate the current through the capacitor C = 0.1μF with the voltage as shown: **$v(t) = 5(1-e^{-t/10^{-6}})$**



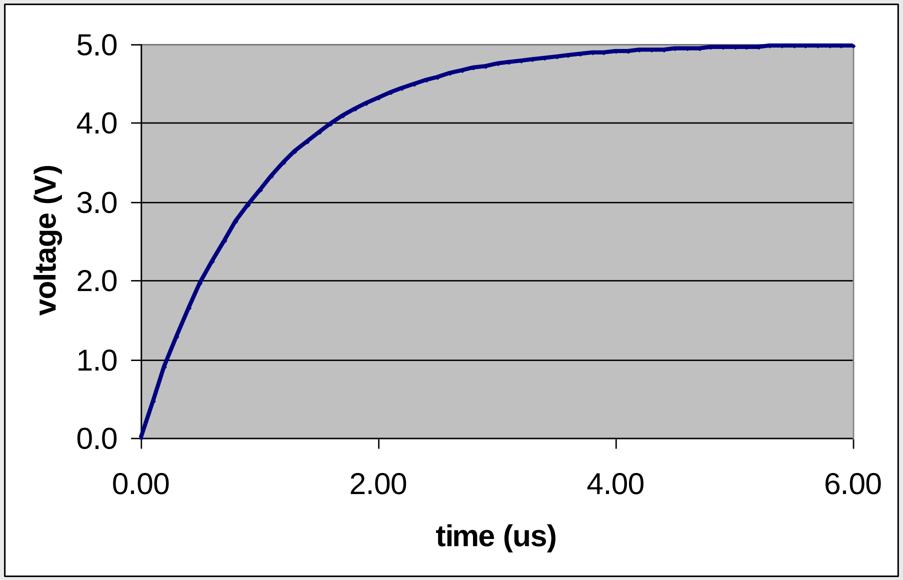
$$i(t) = C\frac{dv(t)}{dt}$$

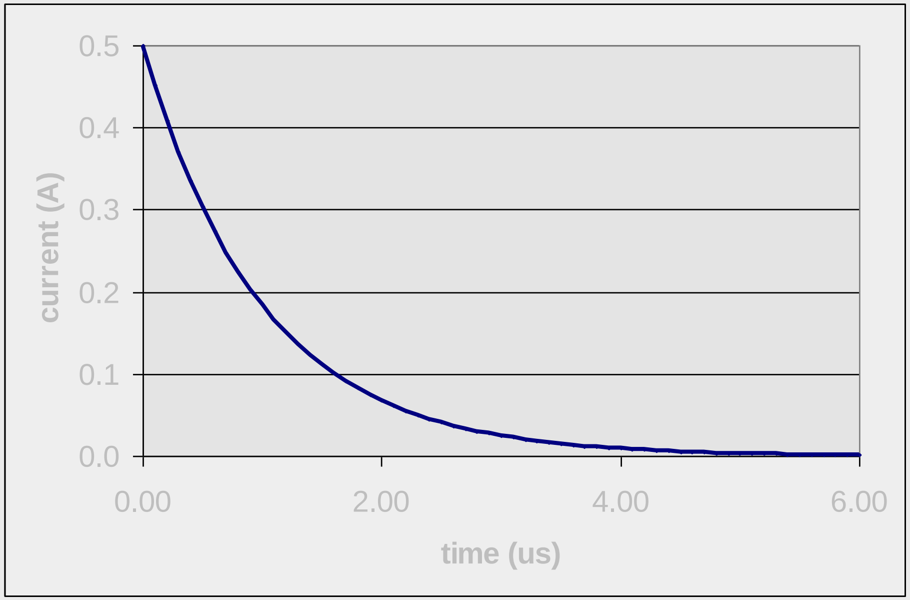
$$= (10^{-7})\frac{5}{10^{-6}}e^{-t/10^{-6}}$$

$$= 0.5e^{-t/10^{-6}}A$$

Ideal Capacitor

- **<u>Example2</u>**: calculate the current through the capacitor C = 0.1μF with the voltage as shown: $\mathbf{v(t) = 5(1-e^{-t/10^{-6}})}$



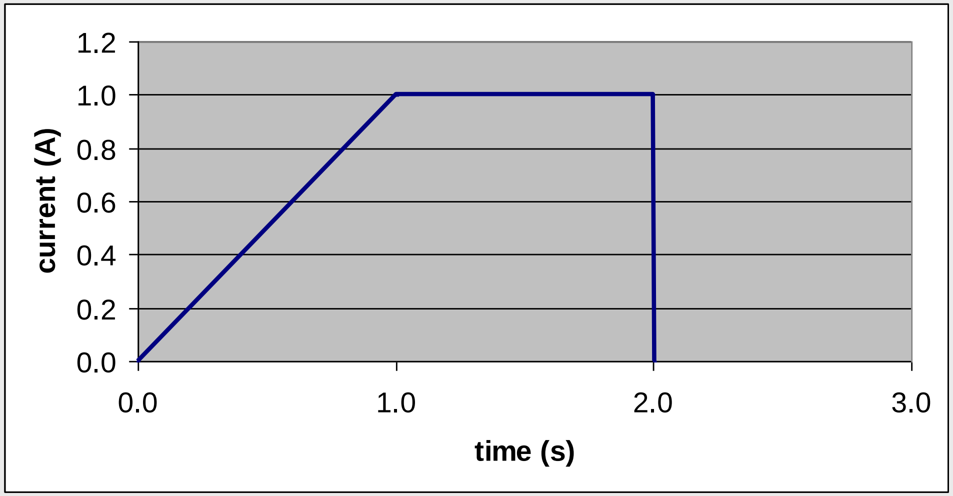


NB: the capacitor's current jumps '**instantaneously**' to 0.5A. The ability of a capacitor's current to change instantaneously is an important property of capacitors

$$i(t) = 0.5e^{-t/10^{-6}}\ A$$

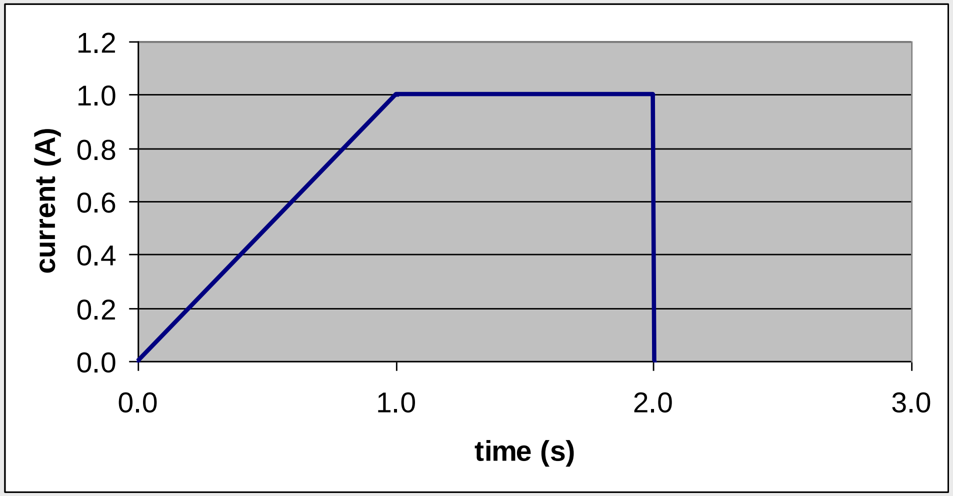
Ideal Capacitor

- **Example3**: find the voltage v(t) for a capacitor C = 0.5F with the current as shown and v(0) = 0



Ideal Capacitor

- **Example3**: find the voltage v(t) for a capacitor C = 0.5F with the current as shown and v(0) = 0

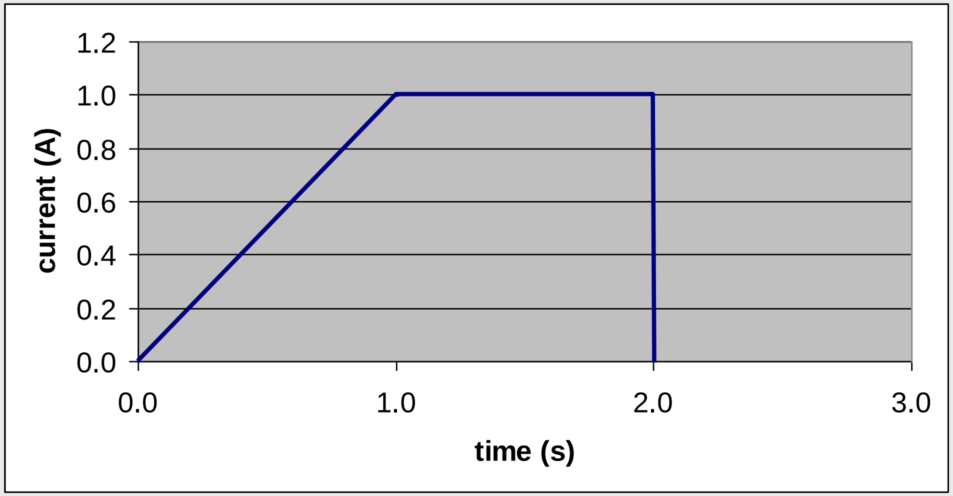


Interval	current $i(t)$
$t \le 0$	0
$0 < t \le 1$	t
$1 < t \le 2$	1
$2 < t$	0

$$v(t) = \frac{1}{C}\int_0^t i\,d\tau + v(0)$$

Ideal Capacitor

- **Example3**: find the voltage v(t) for a capacitor C = 0.5F with the current as shown and v(0) = 0

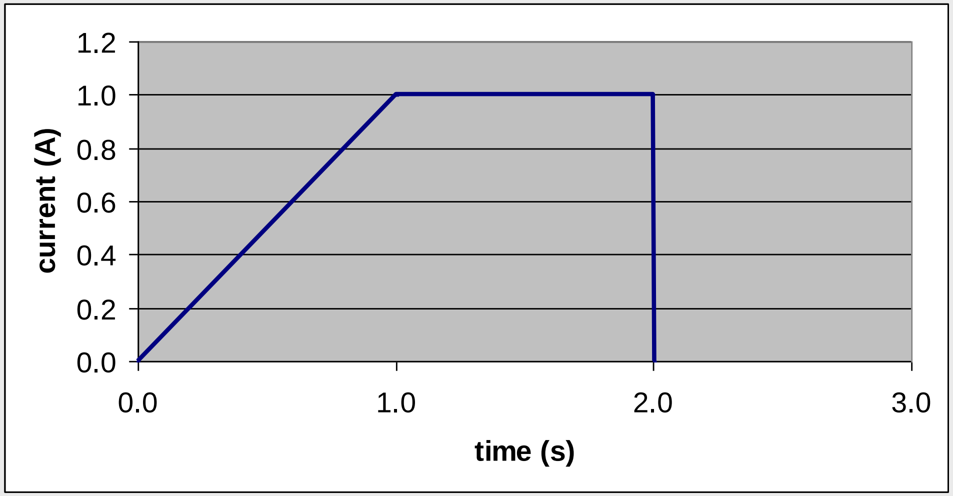


Interval	voltage $v(t)$
$t \le 0$	0
$0 < t \le 1$	$2\int_0^t \tau d\tau + 0$
$1 < t \le 2$	$2\int_0^t (1) d\tau + v(1)$
$2 < t$	$0 + v(2)$

$$v(t) = \frac{1}{C}\int_0^t i d\tau + v(0)$$

Ideal Capacitor

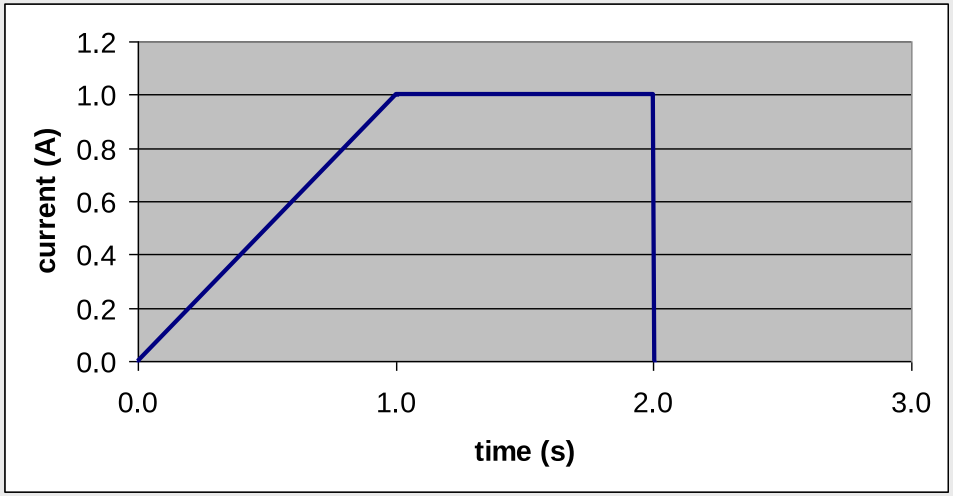
- **Example3**: find the voltage v(t) for a capacitor C = 0.5F with the current as shown and v(0) = 0

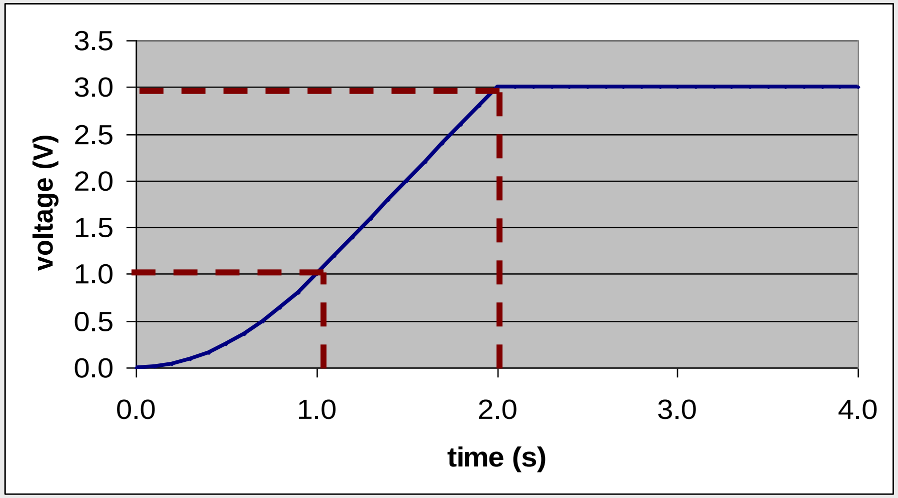


Interval	voltage $v(t)$
$t \le 0$	0
$0 < t \le 1$	t^2
$1 < t \le 2$	$2t - 1$
$2 < t$	3

Ideal Capacitor

- **<u>Example3</u>**: find the voltage v(t) for a capacitor C = 0.5F with the current as shown and v(0) = 0





NB: The final value of the capacitor voltage after the current source has stopped charging the capacitor depends on two things:

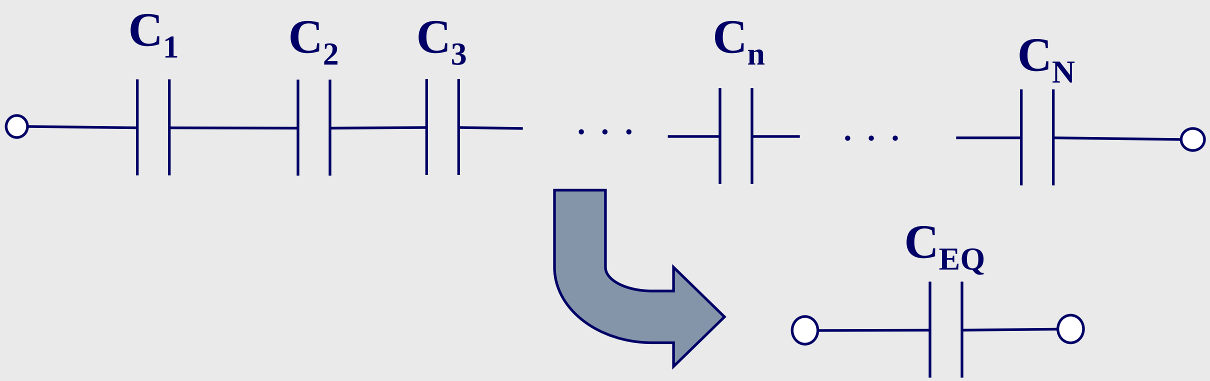
1. The initial capacitor voltage
2. The history of the capacitor current

Interval	voltage $v(t)$
$t \leq 0$	0
$0 < t \leq 1$	t^2
$1 < t \leq 2$	$2t - 1$
$2 < t$	3

Series Capacitors

- **Capacitor Series Rule**: two or more circuit elements are said to be **in series** if the current from one element *exclusively* flows into the next element.
  - Capacitors in **series** add the same way resistors in **parallel** add

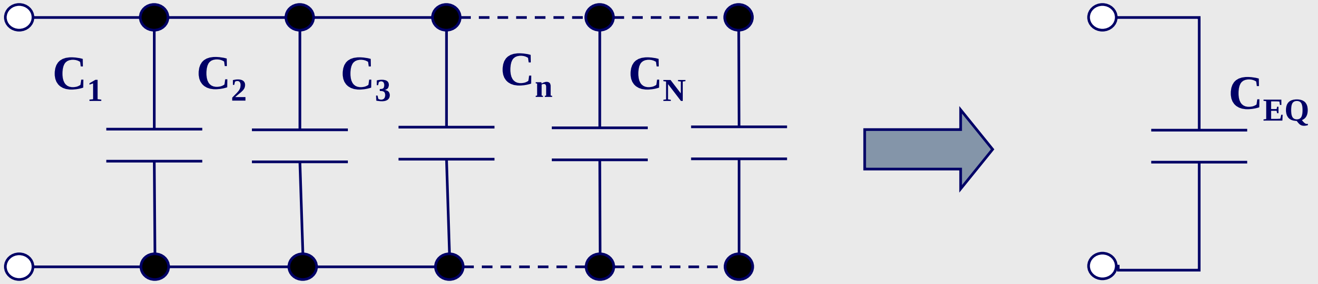
$$\frac{1}{C_{EQ}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots \frac{1}{C_N} \qquad C_{EQ} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots + \frac{1}{C_N}}$$



Parallel Capacitors

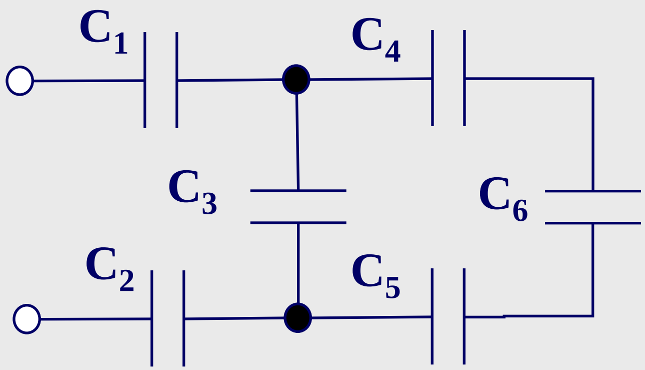
- **Parallel Rule**: two or more circuit elements are said to be **in parallel** if the elements share the *same* terminal**s**
  - Capacitors in **parallel** add the same way resistors in **series** add

$$C_{EQ} = \sum_{n=1}^{N} C_n$$



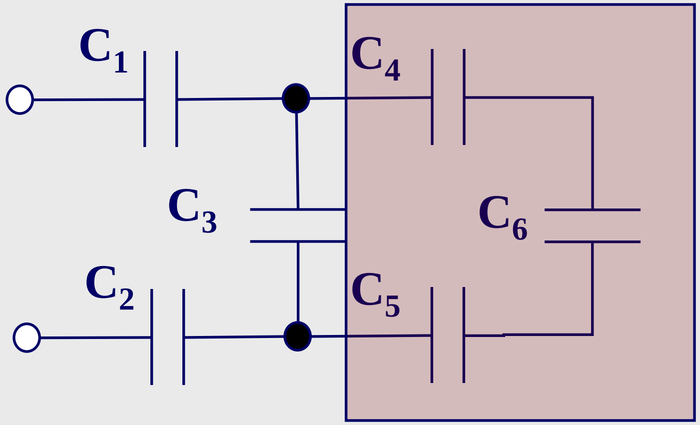
Parallel and Series Capacitors

- **<u>Example4</u>**: determine the equivalent capacitance $\mathbf{C_{EQ}}$
  - $\mathbf{C_1}$ = 2mF, $\mathbf{C_2}$ = 2mF, $\mathbf{C_3}$ = 1mF, $\mathbf{C_4}$ = 1/3mF, $\mathbf{C_5}$ = 1/3mF, $\mathbf{C_6}$ = 1/3mF



Parallel and Series Capacitors

- **Example4**: determine the equivalent capacitance $\mathbf{C_{EQ}}$
  - $\mathbf{C_1}$ = 2mF, $\mathbf{C_2}$ = 2mF, $\mathbf{C_3}$ = 1mF, $\mathbf{C_4}$ = 1/3mF, $\mathbf{C_5}$ = 1/3mF, $\mathbf{C_6}$ = 1/3mF



$$C_{EQ1} = \frac{C_4C_5C_6}{C_4C_5 + C_4C_6 + C_5C_6}$$

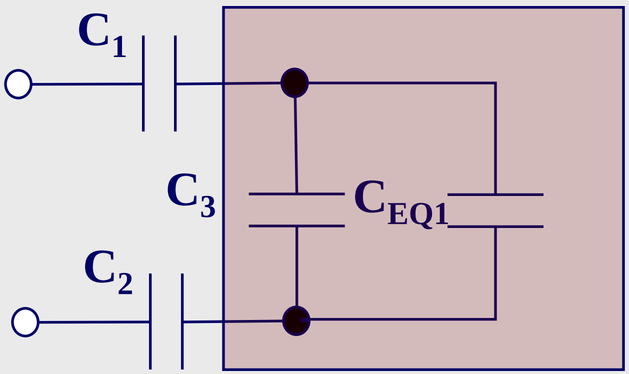
$$= \frac{(1/3)(1/3)(1/3)}{(1/3)(1/3) + (1/3)(1/3) + (1/3)(1/3)}$$

$$= \frac{1/27}{1/3}$$

$$= \frac{1}{9}\, mF$$

Parallel and Series Capacitors

- **Example4**: determine the equivalent capacitance $\mathbf{C_{EQ}}$
  - $\mathbf{C_1}$ = 2mF, $\mathbf{C_2}$ = 2mF, $\mathbf{C_3}$ = 1mF, $\mathbf{C_4}$ = 1/3mF, $\mathbf{C_5}$ = 1/3mF, $\mathbf{C_6}$ = 1/3mF

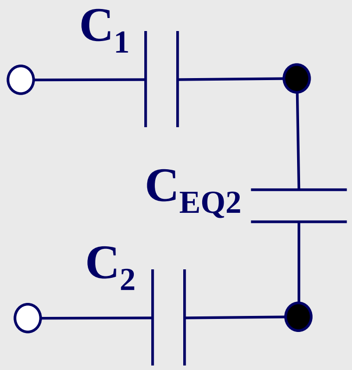


$$C_{EQ1} = \frac{1}{9} mF$$

$$C_{EQ2} = C_3 + C_{EQ1} = (1) + \left(\frac{1}{9}\right) = \frac{10}{9} mF$$

Parallel and Series Capacitors

- **Example4**: determine the equivalent capacitance $\mathbf{C_{EQ}}$
  - $\mathbf{C_1}$ = 2mF, $\mathbf{C_2}$ = 2mF, $\mathbf{C_3}$ = 1mF, $\mathbf{C_4}$ = 1/3mF, $\mathbf{C_5}$ = 1/3mF, $\mathbf{C_6}$ = 1/3mF

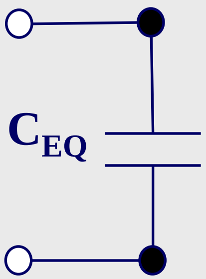


$$C_{EQ2} = \frac{10}{9}\, mF$$

$$C_{EQ} = \frac{C_1 C_2 C_{EQ2}}{C_1 C_2 + C_1 C_{EQ2} + C_2 C_{EQ2}}$$
$$= \frac{(2)(2)(10/9)}{(2)(2) + (2)(10/9) + (2)(10/9)}$$
$$= \frac{40/9}{4 + 20/9 + 20/9}$$
$$= \frac{10}{19}\, mF$$

Parallel and Series Capacitors

- **Example4**: determine the equivalent capacitance $\mathbf{C_{EQ}}$
  - $\mathbf{C_1}$ = 2mF, $\mathbf{C_2}$ = 2mF, $\mathbf{C_3}$ = 1mF, $\mathbf{C_4}$ = 1/3mF, $\mathbf{C_5}$ = 1/3mF, $\mathbf{C_6}$ = 1/3mF



$$C_{EQ} = \frac{10}{19} mF$$

Energy Storage in Capacitors

Capacitor energy $W_C(t)$: can be found by taking the integral of power

- Instantaneous power → $P_C = iv$

$$W_C(t) = \int_{-\infty}^{t} P_C(\tau)d\tau$$
$$= \int_{-\infty}^{t} v_C(\tau)i_C(\tau)d\tau$$
$$= \int_{-\infty}^{t} v_C(\tau)C\frac{dv_C(\tau)}{d\tau}d\tau$$
$$= C\int_{v(-\infty)}^{v(t)} v\,dv$$
$$= \frac{1}{2}Cv^2\Big|_{v(-\infty)}^{v(t)}$$

Since the capacitor is uncharged at **t = -∞**, **v(- ∞) = 0**, thus:

$$W_C(t) = \frac{1}{2}Cv(t)^2 \;\; J$$

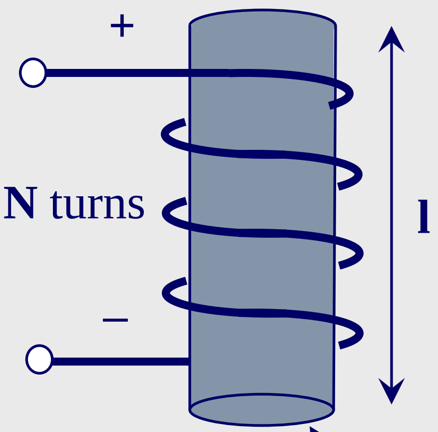
Ideal Inductor

- Inductors are made by winding a coil of wire around a core
  - The core can be an insulator or ferromagnetic material

$$L = \frac{\mu N^2 A}{l + 0.45d}$$

L – Inductance

μ – relative permeability



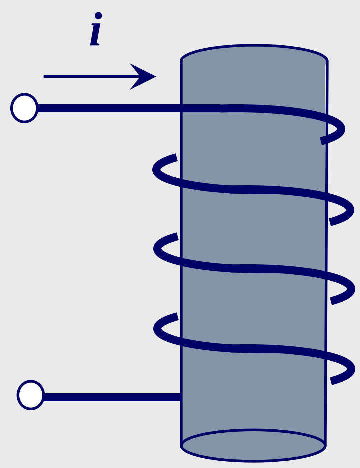
- Cross-sectional area **A**
- Diameter **d**

Ideal Inductor

<u>Inductance</u>: a measure of the ability of a device to store energy in the form of a magnetic field

Ideally the resistance through an inductor is **zero** (i.e. **no voltage drop**), thus an inductor acts like a **short circuit** in the presence of a **DC source.**

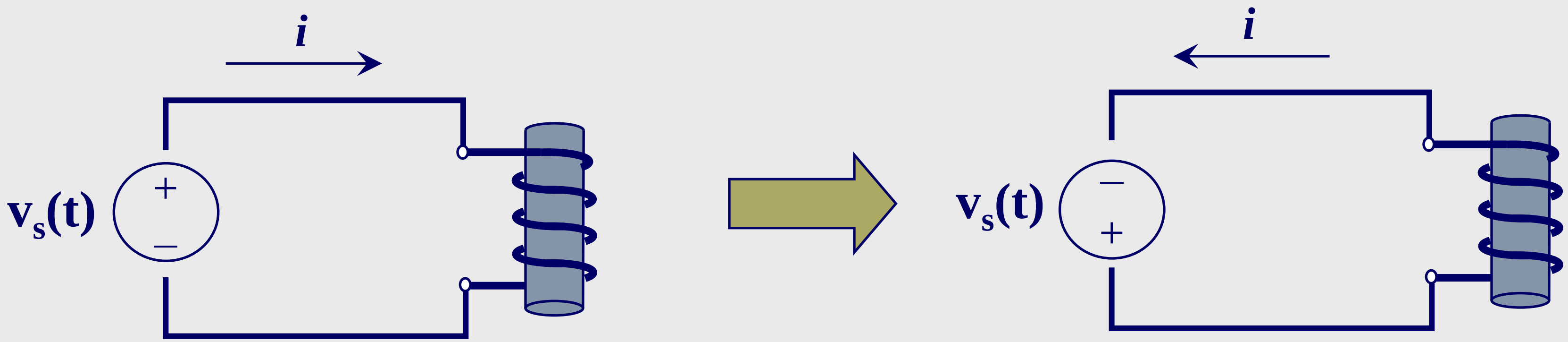
BUT there is an **initial** voltage across the inductor as the current builds up (much like 'charging' with capacitors)



<u>Henry (*H*)</u>: unit of inductance.
1 henry = 1 volt-second/ampere (V-s/A)

Ideal Inductor

- **<u>Inductor with an AC source</u>**: since AC sources periodically reverse current directions, the current flow through the inductor also changes
  - With each current direction change, the current through the inductor must 'build up', thus there is a continual voltage drop across the inductor
  - Just as with a DC source, **current across an inductor cannot change instantaneously**



Ideal Inductor

- I – v characteristic for an ideal inductor

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

$$i(t) = \frac{1}{L}\int_{-\infty}^{t} v_L(\tau)d\tau$$

NB: note the **duality** between inductors and capacitors

BYU Electrical Engineering Computer Engineering

Ideal Inductor

- i – v characteristic for an ideal inductor

$$i(t) = \frac{1}{L}\int_{-\infty}^{t} v_L(\tau)d\tau$$

NB: Assumes we know the value of the inductor from time (**τ = -∞**) until time (**τ** = t)

Instead

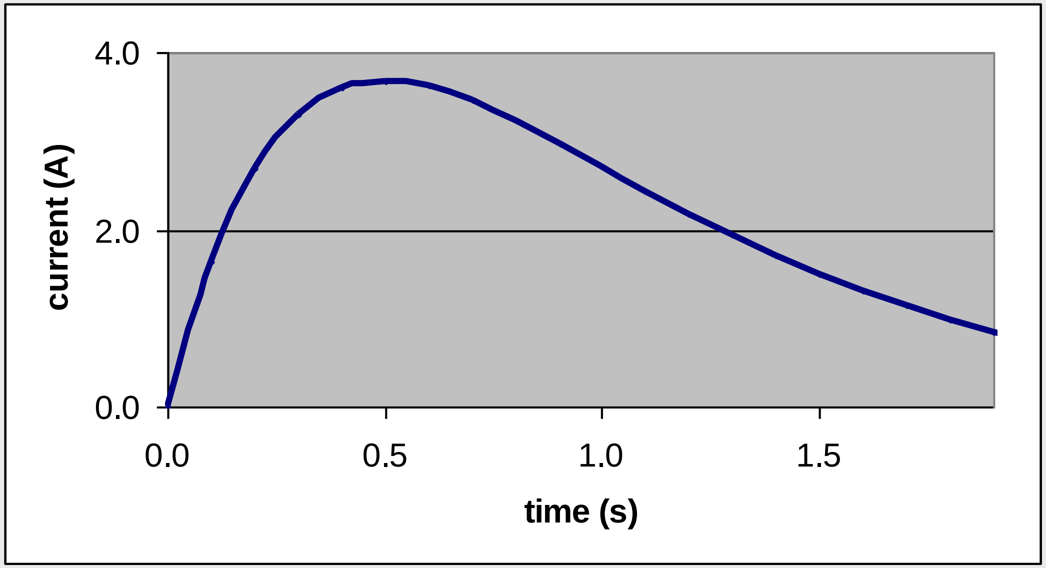
$$i(t) = \frac{1}{L}\int_{t_0}^{t} v_L(\tau)d\tau + i(t_0)$$

Initial time (often $\mathbf{t_0}$ = 0)

Initial condition

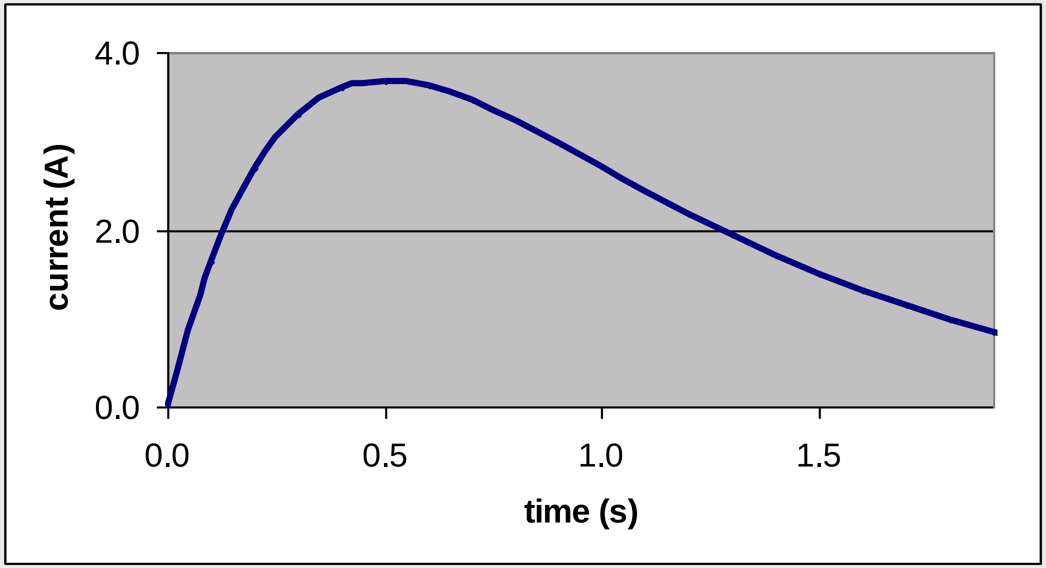
Ideal Inductor

- **Example5**: find the voltage across an inductor L = 0.1H when the current is: $\mathbf{i(t) = 20\ t\ e^{-2t}}$



Ideal Inductor

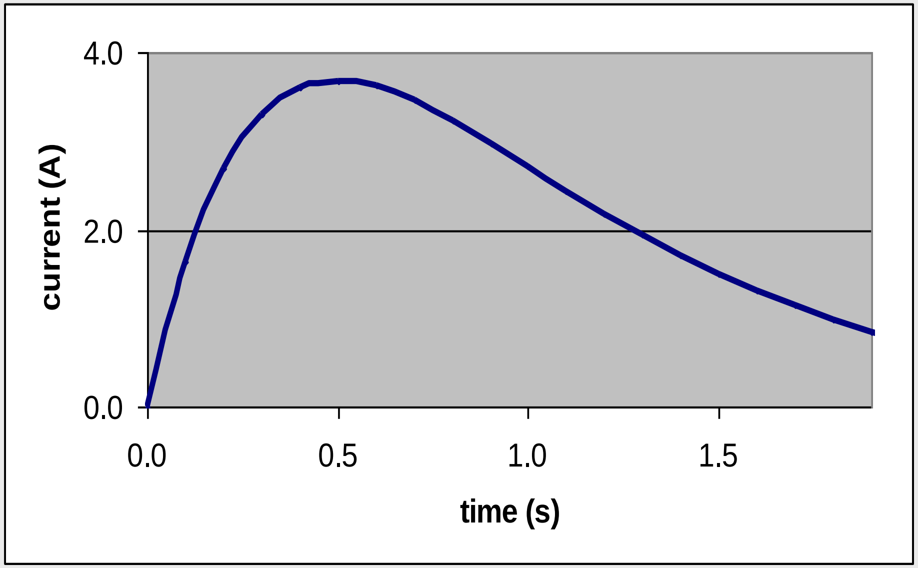
- **<u>Example5</u>**: find the voltage across an inductor L = 0.1H when the current is: $\mathbf{i(t) = 20\ t\ e^{-2t}}$

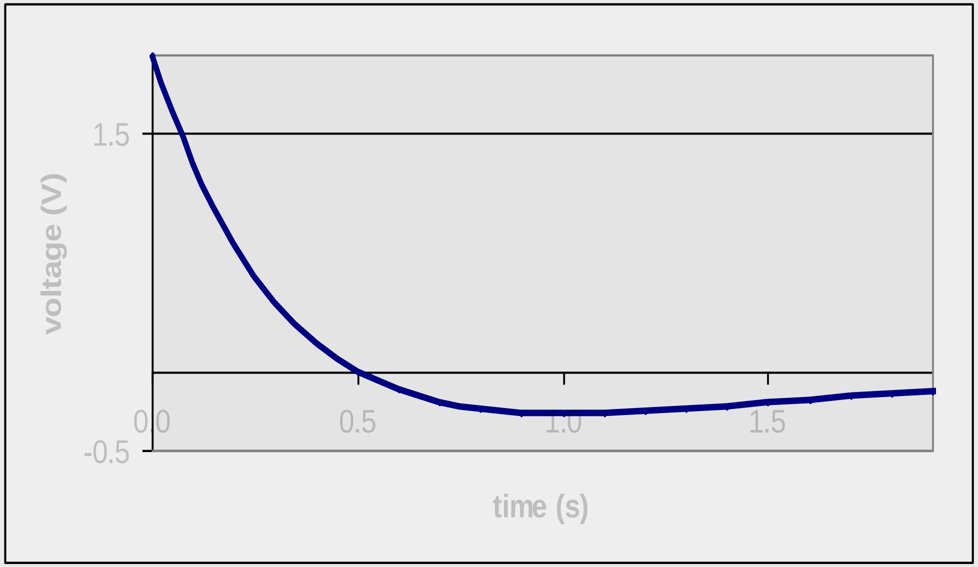


$$v(t) = L\frac{di(t)}{dt}$$
$$= 0.1\frac{d}{dt}(20te^{-2t})$$
$$= 2(-2te^{-2t} + e^{-2t})$$
$$= 2e^{-2t}(1-2t)V$$

Ideal Inductor

- **<u>Example5</u>**: find the voltage across an inductor L = 0.1H when the current is: $\mathbf{i(t) = 20\, t\, e^{-2t}}$





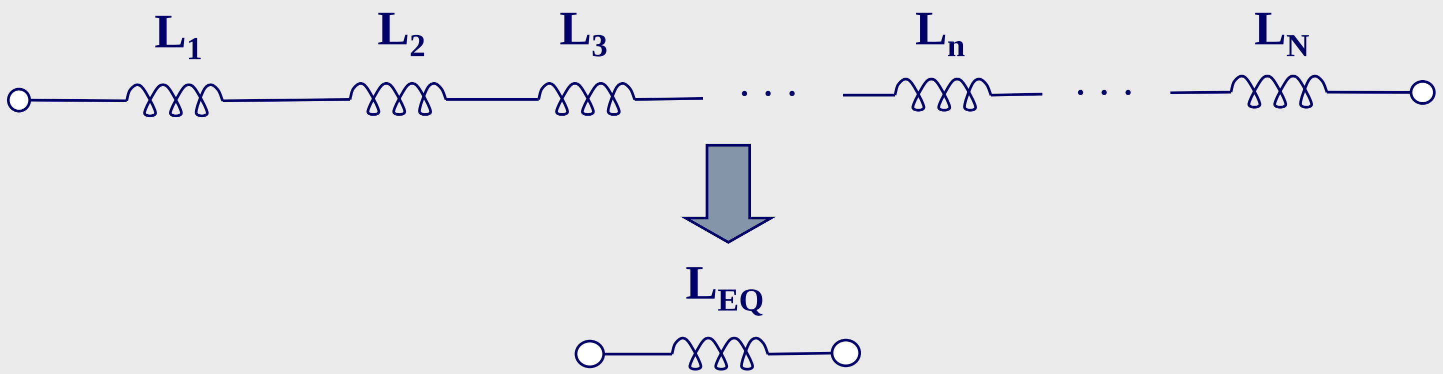
NB: the inductor's voltage jumps '**instantaneously**' to 2V. The ability of an inductor's voltage to change instantaneously is an important property of inductors

$$v(t) = 2e^{-2t}(1-2t)V$$

Series Inductors

- **<u>Series Rule</u>**: two or more circuit elements are said to be **in series** if the current from one element *exclusively* flows into the next element.
  - Inductors in **series** add the same way resistors in **series** add

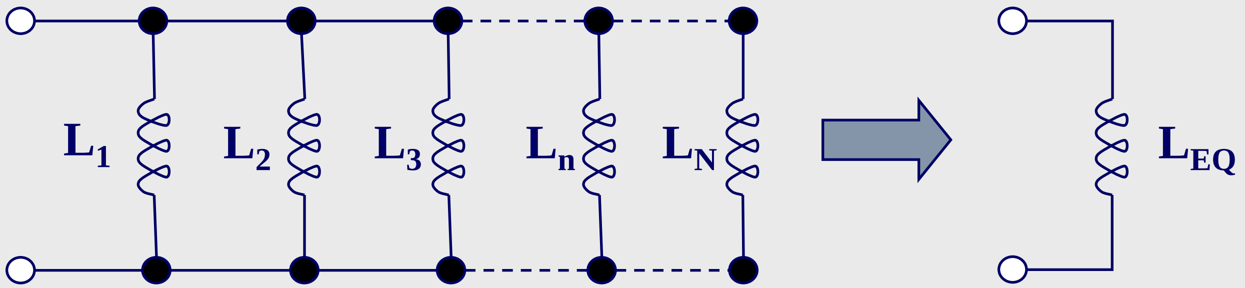
$$L_{EQ} = \sum_{n=1}^{N} L_n$$



Parallel Inductors

- **Parallel Rule**: two or more circuit elements are said to be **in parallel** if the elements share the *same* terminal**s**
  - Inductors in **parallel** add the same way resistors in **parallel** add

$$\frac{1}{L_{EQ}} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \cdots \frac{1}{L_N} \qquad L_{EQ} = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \cdots + \frac{1}{L_N}}$$



Energy Storage in Capacitors

Capacitor energy $W_L(t)$: can be found by taking the integral of power

- Instantaneous power → $\mathbf{P_L = iv}$

$$W_L(t) = \int_{-\infty}^{t} P_L(\tau)d\tau$$

$$= \int_{-\infty}^{t} v_L(\tau)i_L(\tau)d\tau$$

$$= \int_{-\infty}^{t} L\frac{di_L(\tau)}{d\tau}i_L(\tau)d\tau$$

$$= L\int_{i(-\infty)}^{i(t)} idi$$

$$= \frac{1}{2}Li^2\Big|_{i(-\infty)}^{i(t)}$$

Since the inductor is uncharged at **t = -∞**, **i(- ∞) = 0**, thus:

$$W_L(t) = \frac{1}{2}Li(t)^2 \quad J$$

Energy Storage in Capacitors

- **<u>Example6</u>**: calculate the power and energy stored in a 0.1-H inductor when:
  - $i = 20\, t\, e^{-2t}$ A ($i = 0$ for $t < 0$)
  - $V = 2\, e^{-2t}(1- 2t)$V (for $t >= 0$)

Energy Storage in Capacitors

- **Example6**: calculate the power and energy stored in a 0.1-H inductor when:
  - i = 20 t e^{-2t} A (i = 0 for t < 0)
  - V = 2 e^{-2t} (1- 2t)V (for t >= 0)

$$P_L(t) = v_L(t) i_L(t)$$
$$= \left[2e^{-2t}(1-2t)\right]\left(20te^{-2t}\right)$$
$$= 40te^{-4t}(1-2t)W$$

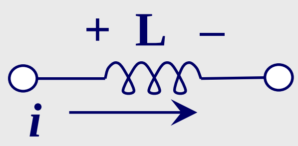
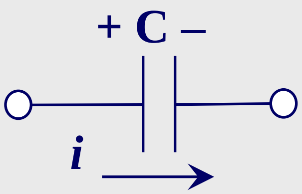
Energy Storage in Capacitors

- **Example6**: calculate the **power** and **energy** stored in a 0.1-H inductor when:
  - $i = 20\,t\,e^{-2t}$ A ($i = 0$ for $t < 0$)
  - $V = 2\,e^{-2t}(1- 2t)$V (for $t >= 0$)

$$P_L(t) = v_L(t)i_L(t)$$
$$= \left[2e^{-2t}(1-2t)\right]\left(20te^{-2t}\right)$$
$$= 40te^{-4t}(1-2t)W$$

$$W_L(t) = \frac{1}{2}Li_L(t)^2$$
$$= \frac{1}{2}(0.1)\left(20te^{-2t}\right)^2$$
$$= 20t^2e^{-4t}J$$

Ideal Capacitors and Inductors

	Inductors	**Capacitors**
Passive sign convention		
Voltage	$v(t) = L\frac{di(t)}{dt}$	$v(t) = \frac{1}{C}\int_{t_0}^{t} i_C(\tau)d\tau + v(t_0)$
Current	$i(t) = \frac{1}{L}\int_{t_0}^{t} v_L(\tau)d\tau + i(t_0)$	$i(t) = C\frac{dv(t)}{dt}$
Power	$P_L(t) = Li(t)\frac{di(t)}{dt}$	$P_C(t) = Cv(t)\frac{dv(t)}{dt}$

Ideal Capacitors and Inductors

	Inductors	Capacitors
Energy	$W_L(t) = \frac{1}{2} L i(t)^2$	$W_C(t) = \frac{1}{2} C v(t)^2$
An **instantaneous** change is **not permitted** in:	Current	Voltage
Will permit an **instantaneous** change in:	Voltage	Current
With **DC source** element acts as a:	Short Circuit	Open Circuit