# Capacitors & Inductors: Energy Storage & Release

EGR 220, Chapter 6

February 28, 2020

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## Finish Maximum Power Transfer (ch 4)

- Useful application of the Thevenin Equivalent Circuit theory.
- Use the simplified, equivalent circuit with one voltage source and a series resistor to determine the maximum power **any circuit** with the equivalent characteristics can supply.
- … the maximum power a given circuit can supply to a load.

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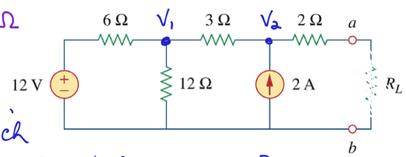
## Maximum Power Transfer

$R_{Th} = 2 + 3 + 6 \| 12 = 9\Omega$ (with $6 \| 12 = 4\Omega$)




$V_{Th} = ?$

first identify which voltage drop(s) in the circuit are $V_{Th}$?
And what role does the 2Ω R play in $V_{Th}$?

$V_{Th} = V_{2A\ source} + V_{2\Omega R}$ because that $= V_{ab}$ & $V_{ab} \equiv V_{Th}$

$V_{2A\ source}$: cannot find this directly

$V_{2\Omega R} = 0$ because $I_{2\Omega} = 0A$ with a-b open

So $V_{Th} = V_2$ try KCL @ $V_1$ & then calc $V_2$

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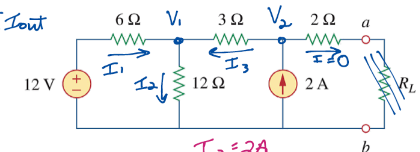
## Maximum Power Transfer

$V_{Th} = V_2$ $\quad \Sigma I_{in} = \Sigma I_{out}$

$I_1 + I_3 = I_2$

$\frac{12 - V_1}{6} + 2A = \frac{V_1 - 0}{12}$



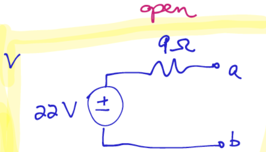

$I_3 = 2A$

all 2A flows through 3Ω since a-b is open

Find $V_1 = 16V$

then $V_{3\Omega} = (3\Omega)(2A) = 6V$

so $V_{Th} = V_2 = 16 + 6 = 22V$

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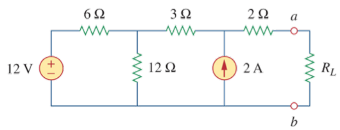
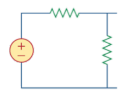
## Maximum Power Transfer



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## Overview: Energy Storage Elements

- Our questions of understanding:
  - V; I; conservation laws
- Energy storage and dynamics
  - Transient behavior & time constant
  - Steady-state behavior
- Introduction to capacitors
  - Matter can store electric charge
  - Create and support an electric field, **E**
- Introduction to inductors
  - Matter responds to moving charge (current) by inducing a voltage drop
  - Create and support a magnetic field, **B**

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## Filling a Bucket with Water → Time

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## Heating/Cooling a Room → Time

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## Natural Response → Charge & Discharge

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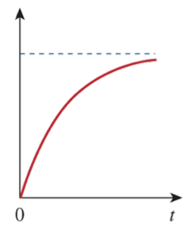
## Natural Response + Steady-State of Dynamic Circuits

- No initial stored energy, charging
- Initial stored energy, discharging
- Initial stored energy, charging

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## Natural Response + Steady-State of Dynamic Circuits

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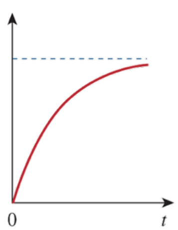


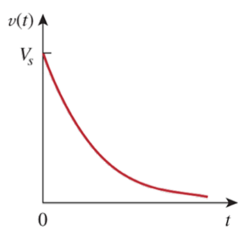


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## Natural Response + Steady-State of Dynamic Circuits

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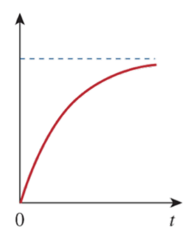


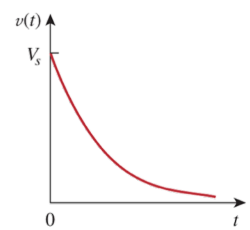


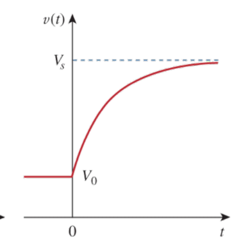


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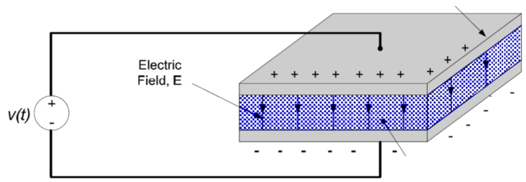
# Capacitors and Stored **E** → Voltage




$C \sim \frac{A}{d}$ & $C = \frac{Q}{V}$

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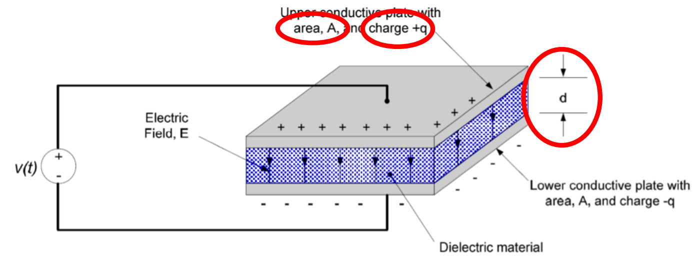
# Capacitors and Stored **E** → Voltage




$C \sim \frac{A}{d}$ & $C = \frac{Q}{V}$ ➢ $Q = CV$ ➢ $\dot{Q} = \frac{dQ}{dt} = i = C\frac{dV}{dt}$

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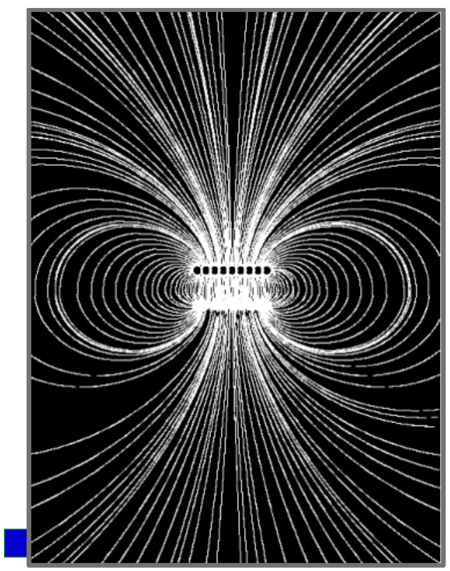
# Capacitors and **E**-field



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# * Capacitors *

- Charge is stored *How*? *Where*?
- Expression: $q$ = __________
- V-I relationship: $\frac{d}{d} = i_c$ =
- Restrictions on the voltage across a capacitor?
  - Think about calculus and taking a derivative
  - What is the steady-state behavior?

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## The 'Constituent Relations' for R, C and L

- ($i.e.$, What is the V-I relationship?)
- R: $V_R$ = ____________; $I_R$ = ______________
- C: $V_c$ = ____________; $I_c$ = ______________
- L: $V_L$ = ____________; $I_L$ = ______________
  (the dual of the expression for C)

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## Equivalent Capacitance

- Property of 'capacitance' $C = {}^{\varepsilon A}/_{d}$
- If plate area, A, increases, what happens to the capacitance?
- If the distance between the plates, d, increases, what happens to capacitance?

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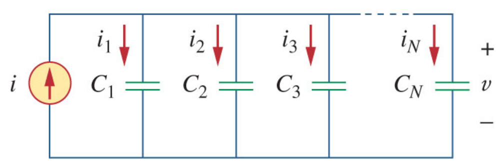
## Capacitors in Parallel: $C_{eq}$=?

$C = {}^{\varepsilon A}/_{d}$

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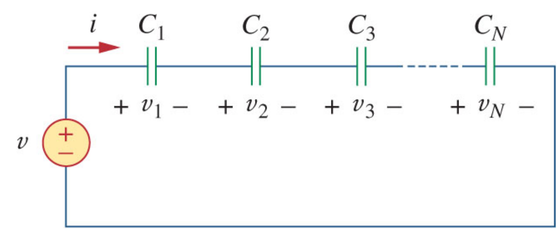
## Capacitors in Series: $C_{eq}$=?

$C = {}^{\varepsilon A}/_{d}$

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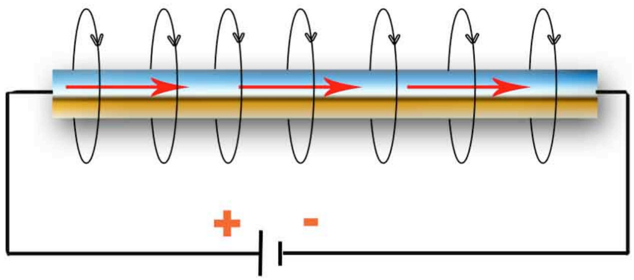
## Inductors and Stored **B**

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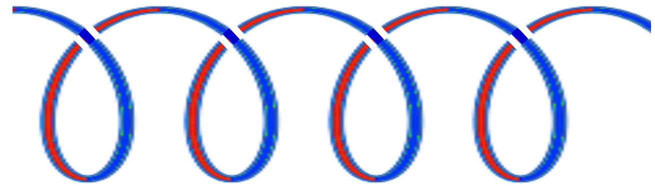
## Inductors and Stored **B**



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## * Inductance *

- How is energy stored?
- Property of inductance – experimental observation:
  - A changing current (not a constant DC value)…
  - “induces” a ______________________
- V-I expression $v_L$ =
- What are the restrictions on the current flowing through an inductor?
  - Think about calculus again
  - What is the steady-state behavior?

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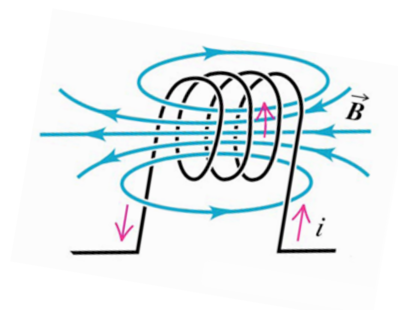
## Equivalent Inductance

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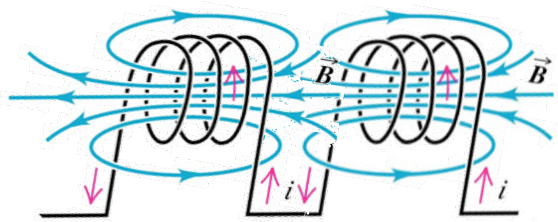
## Equivalent Inductance



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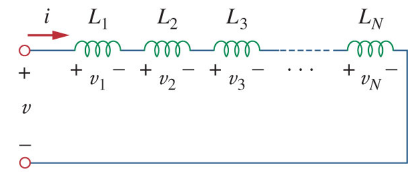
## Series Inductors: $L_{eq}$?



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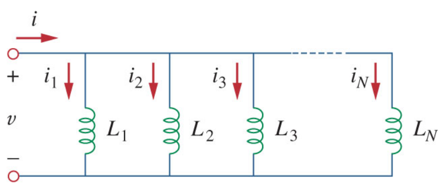
## Parallel Inductors: $L_{eq}$?



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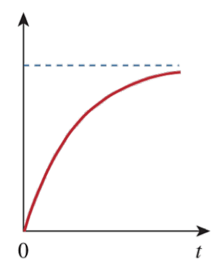
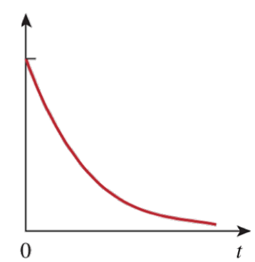
## Natural Response + Steady-State of Dynamic Circuits

No initial stored energy, charging

Initial stored energy, discharging



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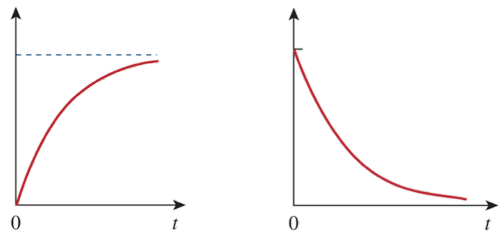
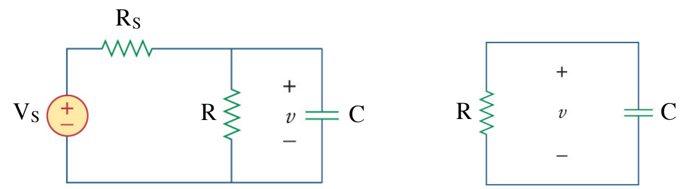
## Next Lab: Explore "time constant"






## Next Lab: Explore "time constant" τ




$\tau = RC$ (Measured in seconds)



## Capacitor & Inductor Concepts

- Know the *v-i* relationship for
  - Resistors
  - Inductors
  - Capacitors
- Know the expressions for series and parallel
  - Resistors
  - Inductors
  - Capacitors



## * Chapter 6 Recap *

- Capacitors and inductors, * ***table 6.1*** *
  - Definition and properties
  - Circuit analysis: *v-i* relationship
  - Series and parallel combinations
  - Form of *v* and *i* are exponential (more in chapter 7)
  - When behavior is as a short or open circuit
- Physical, conservation laws
  - Know whether instantaneous changes in voltage and current are allowed or are impossible across/through elements

# Questions?

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