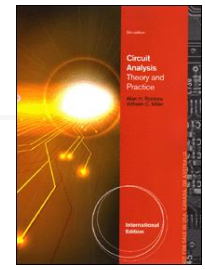
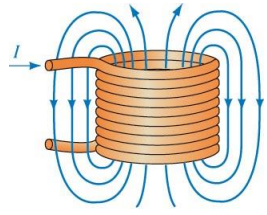


Chapter 13

Inductance and Inductors

Inductors

- Common form of an inductor is a coil of wire
  - Used in radio tuning circuits
- In fluorescent lights
  - Part of ballast circuit
- On power systems
  - Part of the protection circuitry used to control short-circuit currents during faults

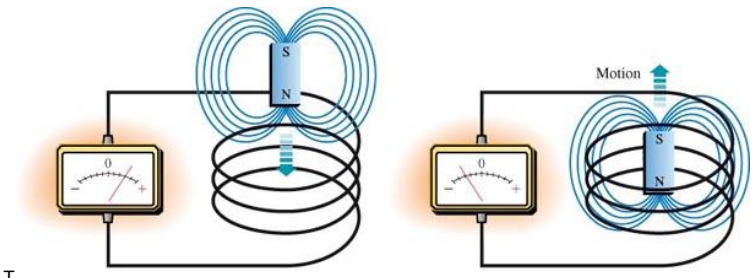


(a) A basic inductor

(b) Ideal inductor symbol

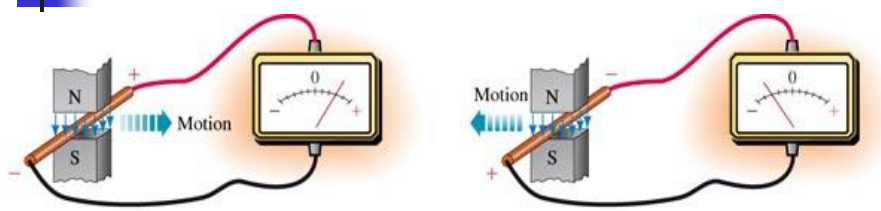
Electromagnetic Induction

- Voltage is induced
  - When a magnet moves through a coil of wire
  - When a conductor moves through a magnetic field
- Change in current in one coil can induce a voltage in a second coil
- Change in current in a coil can induce a voltage in that coil

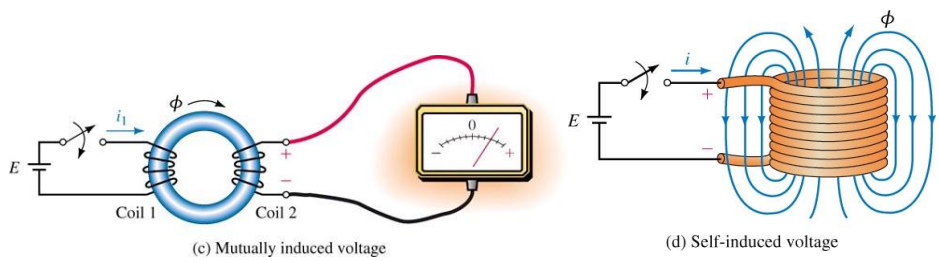


(a) Motional emf

Electromagnetic Induction



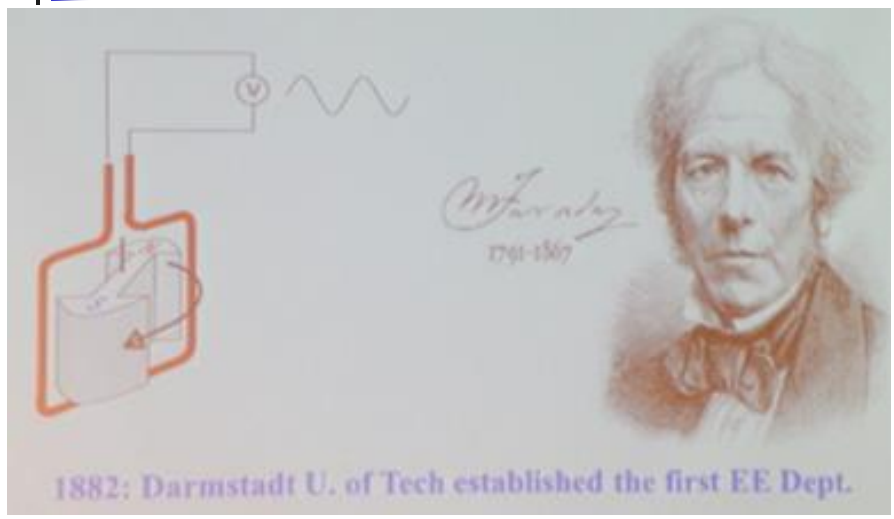
(b) Motional emf



(c) Mutually induced voltage

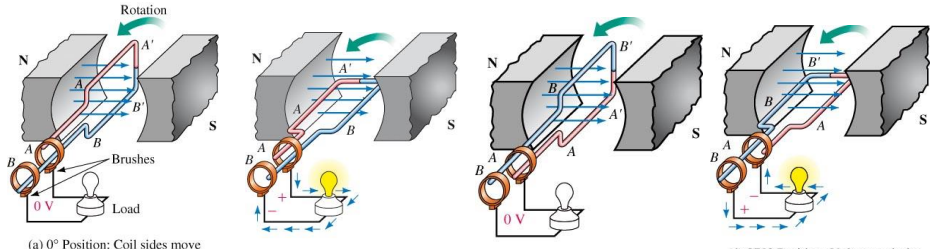
(d) Self-induced voltage

Electromagnetic Induction



Electromagnetic Induction

- **Faraday's Law**
  - Voltage is induced in a circuit whenever the flux linking the circuit is changing
  - Magnitude of voltage is proportional to rate of change of the flux linkages with respect to time
- **Lenz's Law**
  - Polarity of the induced voltage opposes the cause producing it



(a) 0° Position: Coil sides move parallel to flux lines. Since no flux is being cut, induced voltage is zero.

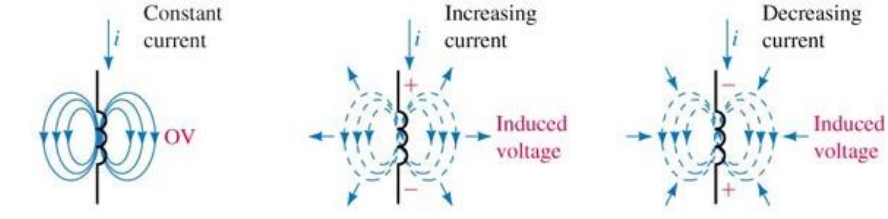
(b) 90° Position: Coil end *A* is positive with respect to *B*. Current direction is out of slip ring *A*.

(c) 180° Position: Coil again cutting no flux. Induced voltage is zero.

(d) 270° Position: Voltage polarity has reversed, therefore, current direction has also reversed.

Induced Voltage and Induction

- If a **constant current** is applied
  - No voltage is induced
- If **current is increased**
  - Inductor will develop a voltage with a polarity to oppose increase
- If **current is decreased**
  - Voltage is formed with a polarity that opposes decrease



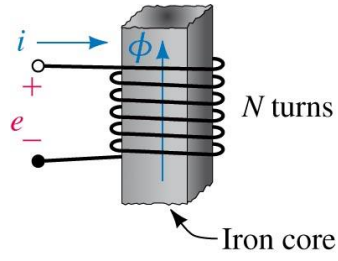
(a) Steady current: Induced voltage is zero.

(b) Increasing current: The induced voltage opposes the current build-up.

(c) Decreasing current: The induced voltage opposes the current decay.

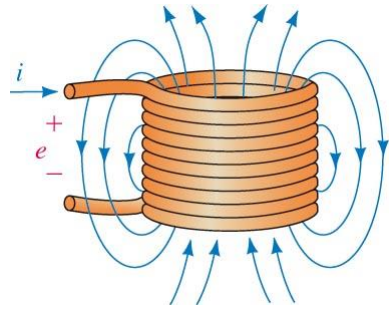
Iron-Core Inductors

- Have flux almost entirely confined to their cores
- Flux lines pass through the windings
- Flux linkage as product
  - Flux times number of turns
- By Faraday's law
  - **Induced voltage** is equal to rate of change of $N\Phi$



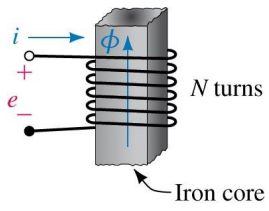
Air-Core Inductors

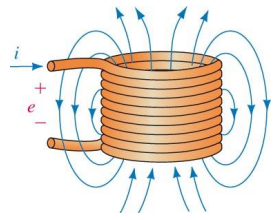
- All flux lines do not pass through all of the windings
- Flux is directly proportional to current
- **Induced voltage** directly proportional to **rate of change of current**

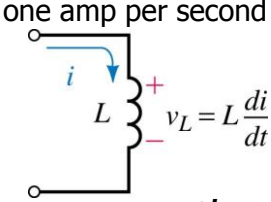


Self-Inductance

- Voltage induced in a coil is proportional to rate of change of the current
- Proportionality constant is *L*
  - Self-inductance of the coil-units are Henrys (H)
- Inductance of a coil is one Henry
  - If the voltage created by its changing current is one volt
  - When its current changes at rate of one amp per second







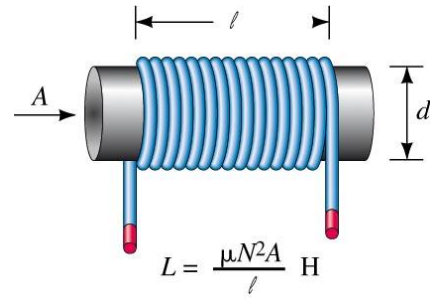
$$v_L = L\frac{\Delta i}{\Delta t}$$

Inductance Formulas

- **Inductance of a coil** is given by

$$L = \frac{\mu N^2 A}{\ell}$$

ℓ *or* l is the length of coil in meters
A is cross-sectional area in square meters
N is number of turns
μ is permeability of core

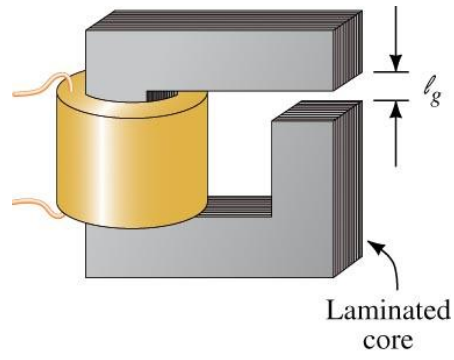


Inductance Formulas

- If **air gap is used**, formula for inductance is

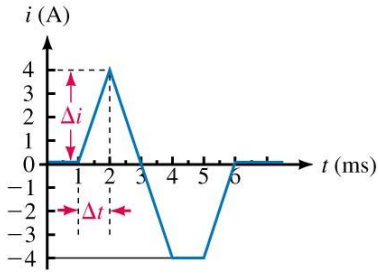
$$L = \frac{\mu_0 N^2 A_g}{\ell_g}$$

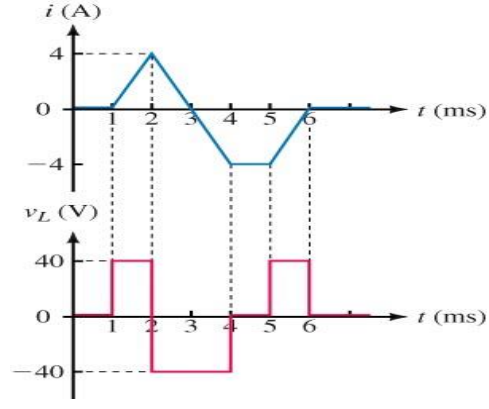
μ_0 is permeability of air
A_g is area of air gap
l_g is length of gap



Computing Induced Voltage

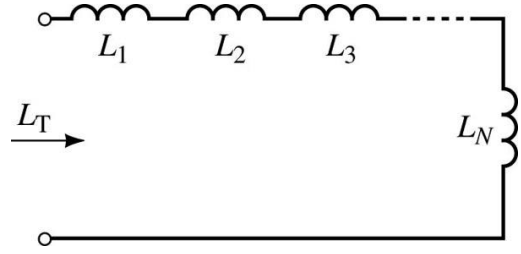
- When using equation $v_L = L\dfrac{\Delta i}{\Delta t}$
  - If current is increasing, voltage is positive
  - If current is decreasing, voltage is negative
  - $\Delta i/\Delta t$ is slope for currents described with straight lines





Inductances in Series

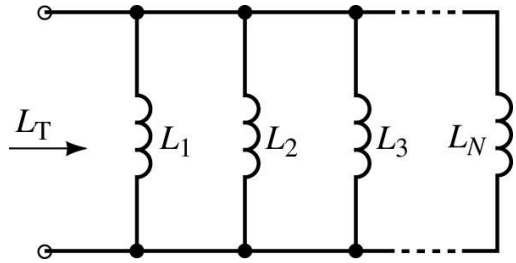
- For inductors in series
  - Total inductance is sum of individual inductors (similar to resistors in series)



$$L_T = L_1 + L_2 + L_3$$

Inductances in Parallel

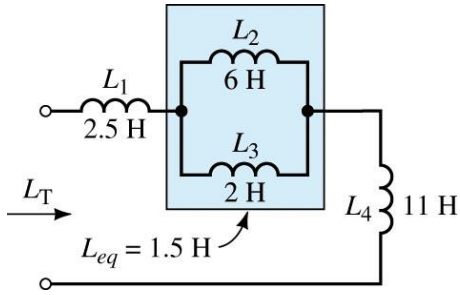
- Inductors in parallel add as resistors do in parallel



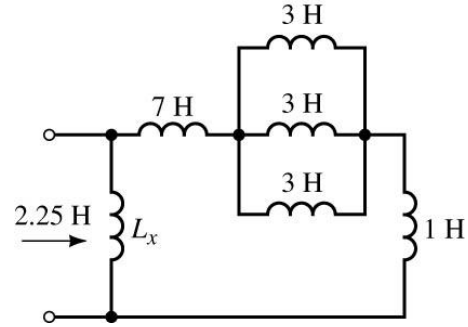
$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}$$

Examples:

Determine L_T

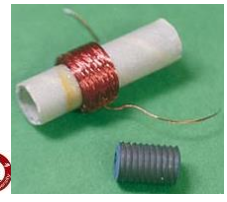


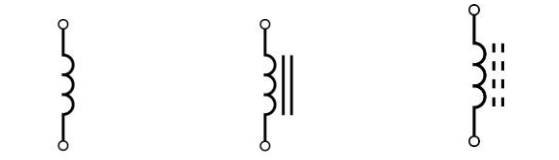
Determine L_x



Core Types

- Type of core depends on intended use and frequency range
- For audio or power supply applications
  - Inductors with iron cores are generally used
- Iron-core inductors
  - Large inductance values but have large power losses at high frequencies
- For high-frequency applications
  - Ferrite-core inductors are used





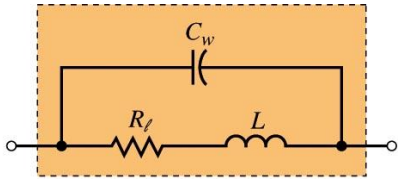
(d) Air-core (a) Iron-core (b) Ferrite-core

Variable Inductors

- Used in tuning circuits
- Inductance may be varied by changing the coil spacing
- Inductance may be changed by moving a core in or out

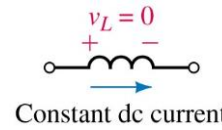
Stray Capacitance & Inductance

- Turns of inductors are separated by insulation
  - May cause stray or parasitic capacitance
- At low frequencies, it can be ignored
  - At high frequencies, it must be taken into account
- Some coils are wound in multiple sections to reduce stray capacitance
- Current-carrying components have some stray inductance
  - Due to magnetic effects of current
- Leads of resistors, capacitors, etc. have inductance
  - These leads are often cut short to reduce stray inductance

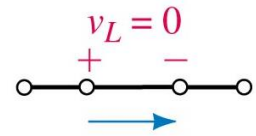


Inductance and **Steady State DC**

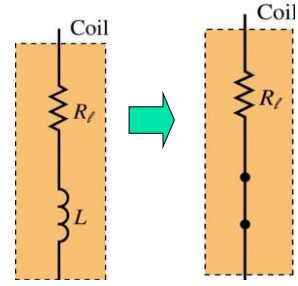
- **Voltage across an inductance** with constant dc current is **zero**



- Since it has current but no voltage, it looks like a short circuit at steady state

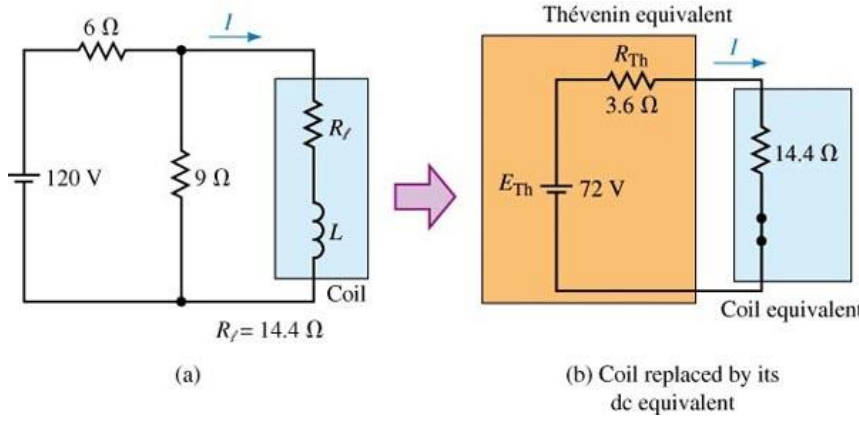


- For non-ideal inductors
  - Resistance of windings must be considered



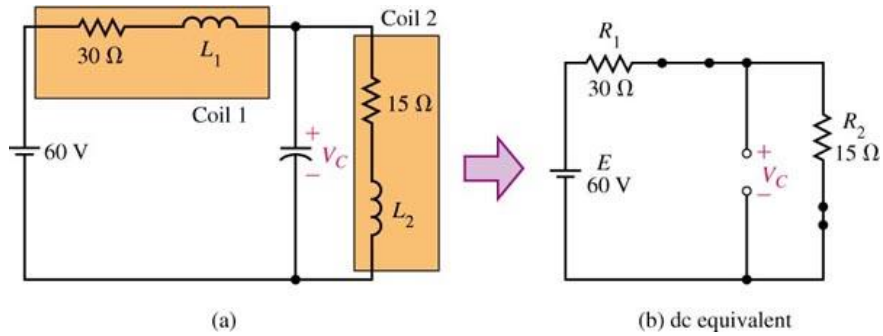
Example:
Inductance and Steady State DC

Determine *I*



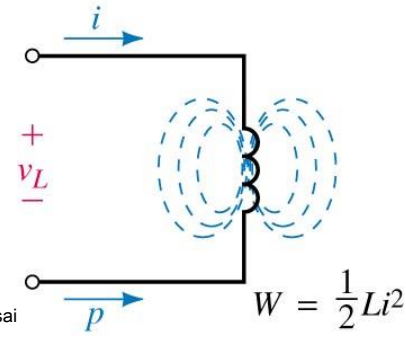
Example:
Inductance and Steady State DC

Determine V_C



Energy Stored by an Inductance

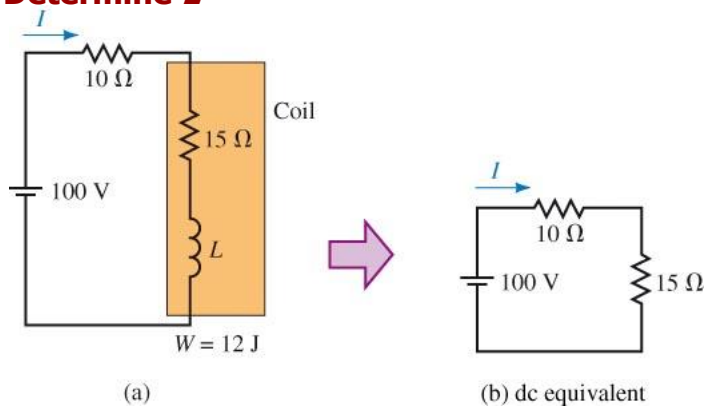
- When energy flows into an inductor
  - Energy is stored in its magnetic field
- When the field collapses
  - Energy returns to the circuit
- No power is dissipated, so there is no power loss



$$W = \frac{1}{2}Li^2$$

Example: Energy Stored by an Inductance

Determine *L*

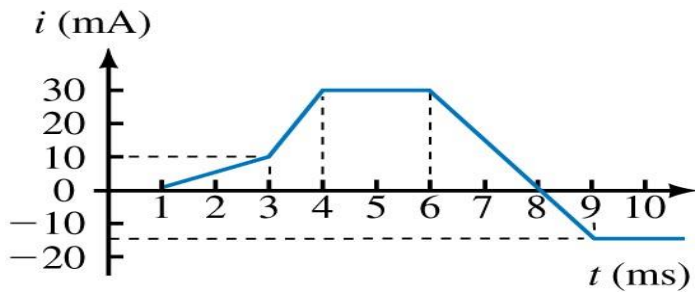


Troubleshooting Hints

- Use ohmmeter
- **Open coil** will have infinite resistance
- Coil can develop shorts between its windings causing excessive current
  - Checking with an ohmmeter may indicate lower resistance

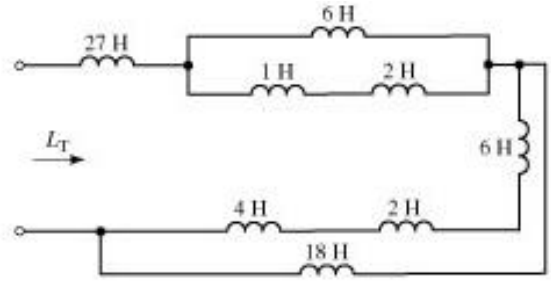
Problem

Determine V_L if L=0.75H



Problem

Determine L_T



Problem

Determine *E* if the circuit is steady state.