Magnetic Field

- A region where magnetic effects can be experienced.
- This magnetic field is represented by **magnetic flux lines**.

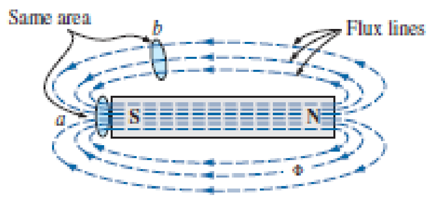


FIG. 1
Flux distribution for a permanent magnet.

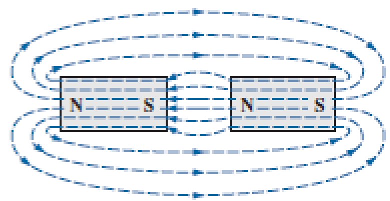


FIG. 2
Flux distribution for two adjacent, opposite poles.

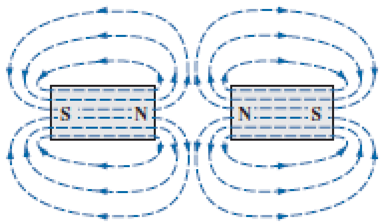


FIG. 3
Flux distribution for two adjacent, like poles.

- The strength of a magnetic field in a particular region is directly related to the density of flux lines in that region.

The **right-hand rule**,

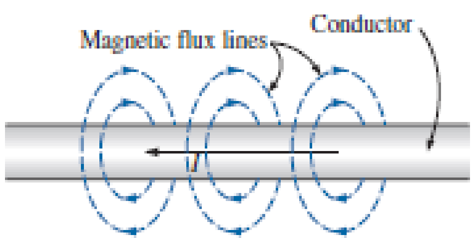
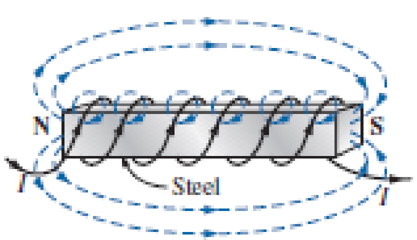
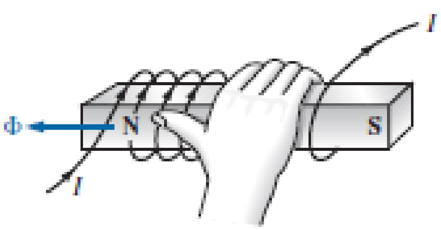


FIG. 6
Magnetic flux lines around a current-carrying conductor.

Thumbs rule,





(a)

Magnetic field (contd.)

- magnetic flux (Φ) is measured in **webers (Wb).**
- The number of flux lines per unit area, called the **flux density, is denoted by B** and is measured in **teslas (T),**

$$\boxed{B = \frac{\Phi}{A}}$$

$$B = \text{Wb/m}^2 = \text{teslas (T)}$$
$$\Phi = \text{webers (Wb)}$$
$$A = \text{m}^2$$

$$\boxed{1 \text{ tesla} = 1 \text{ T} = 1 \text{ Wb/m}^2}$$

- The flux density of an electromagnet is directly related to the number of turns of, and current through, the coil. The product of the two, called the magnetomotive force, is measured in ampere-turns (At) as defined by,

$$\boxed{\mathscr{F} = NI} \qquad \text{(ampere-turns, At)}$$

- the permeability of a material is a measure of the ease with which magnetic flux lines can be established in the material. (Diamagnet, Paramagnet, Ferromagnet)

$$\boxed{\mu_o = 4\pi \times 10^{-7} \text{ Wb/A} \cdot \text{m}} \qquad \boxed{\mu_r = \frac{\mu}{\mu_o}}$$

Inductance

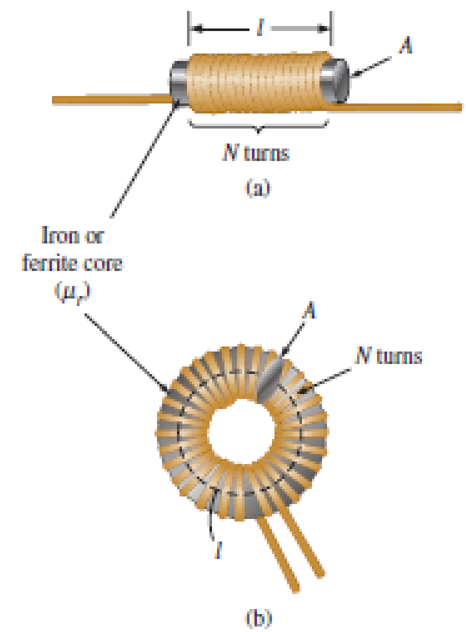


FIG. 16

- inductors are designed to set up a strong magnetic field linking the unit, whereas capacitors are designed to set up a strong electric field between the plates.

- Inductance is measured in **henries (H).**

- 1 henry is the inductance level that will establish a voltage of 1 volt across the coil due to a change in current of 1 A/s through the coil.

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

μ = permeability (Wb/A · m)
N = number of turns (t)
A = m^2
l = m
L = henries (H)

$$L = \frac{\mu_r \mu_o N^2 A}{l}$$

$$\boxed{L = 4\pi \times 10^{-7} \frac{\mu_r N^2 A}{l}} \quad \text{(henries, H)}$$

$$\boxed{L = \mu_r L_o}$$

- The inductance of an inductor with a ferromagnetic core is μ_r times the inductance obtained with an air core.

Inductors

- Types of inductors:
  1. Fixed, 2. Variable, 3. Ferromagnetic core, 4. Tapped

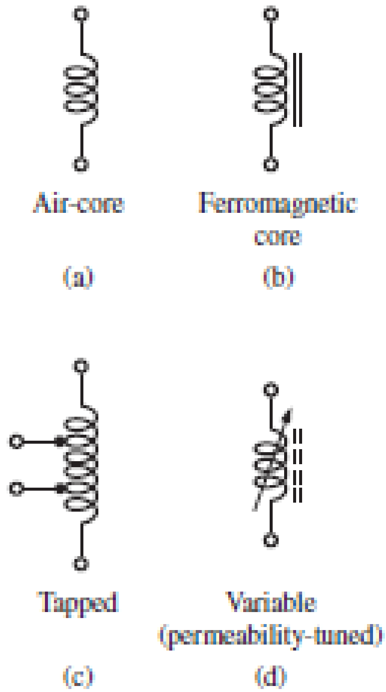


FIG. 20
Inductor (coil) symbols.

Induced Voltage V_L

- **Faraday's law of electromagnetic induction:**

If we move a conductor through a magnetic field so that it cuts magnetic lines of flux, a voltage is induced across the conductor that can be measured with a voltmeter.

$$\boxed{e = N\frac{d\phi}{dt}} \quad \text{(volts, V)}$$

$$\boxed{L = N\frac{d\phi}{di_L}} \quad \text{(henries, H)}$$

$$\boxed{e_L = L\frac{di_L}{dt}} \quad \text{(volts, V)}$$

$$\boxed{v_L = L\frac{di_L}{dt}} \quad \text{(volts, V)}$$

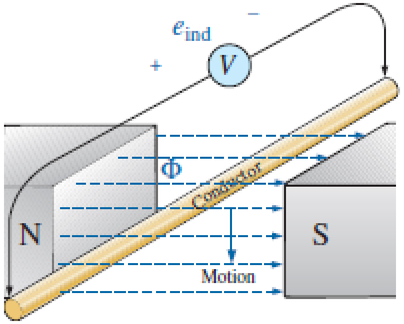
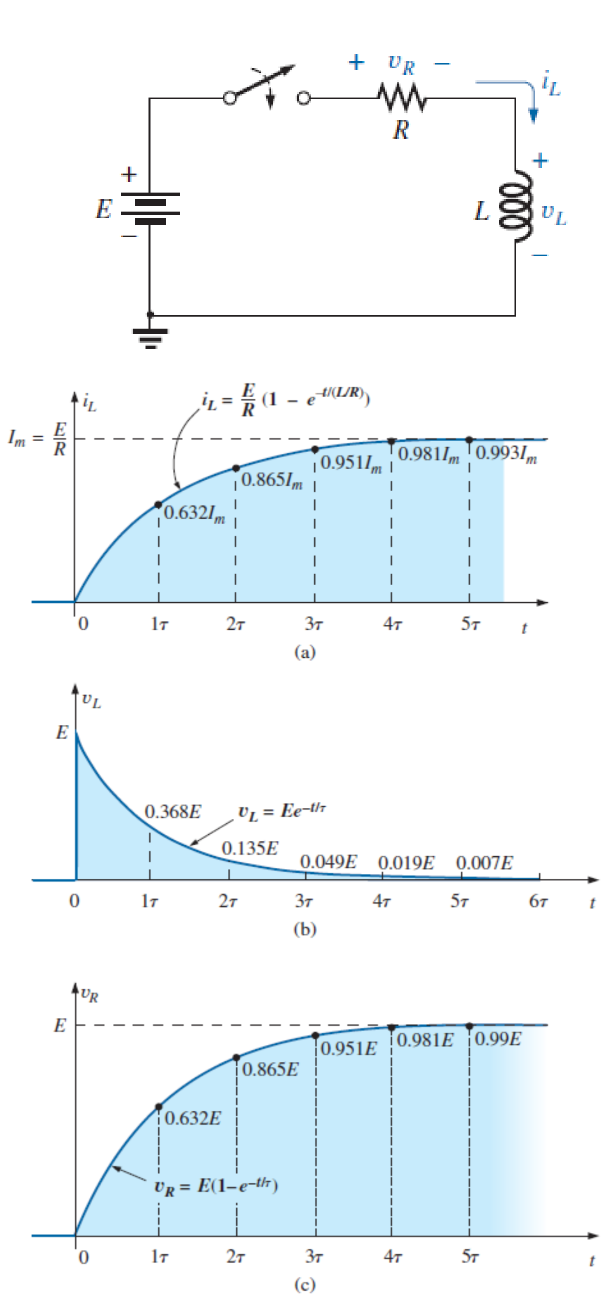


FIG. 28

Generating an induced voltage by moving a conductor through a magnetic field.

• the larger the inductance and/or the more rapid the change in current through a coil, the larger will be the induced voltage across the coil.

R-L TRANSIENTS: THE STORAGE PHASE



- At the instant the switch is closed, the choking action of the coil prevents an instantaneous change in current through the coil, resulting in i_L = 0 A, as shown in Fig.(a). The absence of a current through the coil and circuit at the instant the switch is closed results in zero volts across the resistor as determined by $y_R = i_R R = i_L R$ = (0 A)R = 0 V, as shown in Fig.(c). Applying Kirchhoff's voltage law around the closed loop results in E volts across the coil at the instant the switch is closed, as shown in Fig.(b).
- Initially, the current increases very rapidly, as shown in Fig.(a) and then at a much slower rate as it approaches its steady-state value determined by the parameters of the network (E/R). The voltage across the resistor rises at the same rate because $y_R = i_R R = i_L R$. Since the voltage across the coil is sensitive to the rate of change of current through the coil, the voltage will be at or near its maximum value early in the storage phase. Finally, when the current reaches its steady-state value of E/R amperes, the current through the coil ceases to change, and the voltage across the coil drops to zero volts. At any instant of time, the voltage across the coil can be determined using Kirchhoff's voltage law in the following manner: $y_L = E - y_R$.

R-L TRANSIENTS: THE STORAGE PHASE (contd.)

$$\boxed{i_L = \frac{E}{R}(1 - e^{-t/\tau})}$$ (amperes, A)

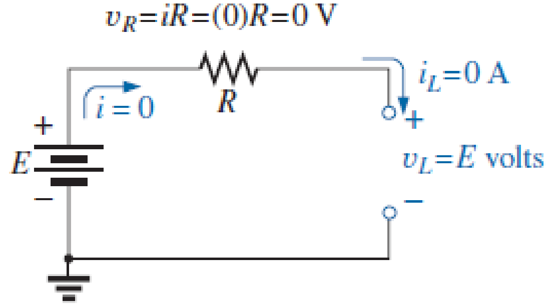
$$\boxed{\tau = \frac{L}{R}}$$ (seconds, s)

$$\boxed{i_L = I_f + (I_i - I_f)e^{-t/\tau}}$$

$$\boxed{v_L = Ee^{-t/\tau}}$$ (volts, V)

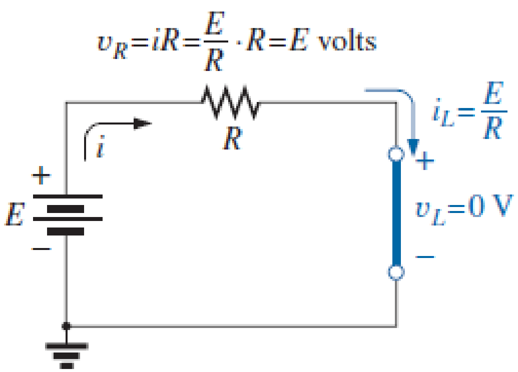
$$\boxed{v_R = E(1 - e^{-t/\tau})}$$ (volts, V)

- the current cannot change instantaneously in an inductive network.
- the inductor takes on the characteristics of an open circuit at the instant the switch is closed.

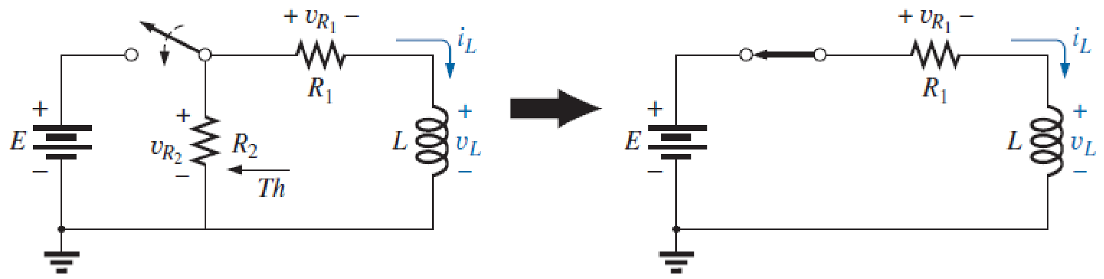


- the inductor takes on the characteristics of a short circuit when steady-state conditions have been established.

$$\boxed{i_L = I_f + (I_i - I_f)e^{-t/\tau}}$$



R-L TRANSIENTS: THE RELEASE PHASE



(a) (b)

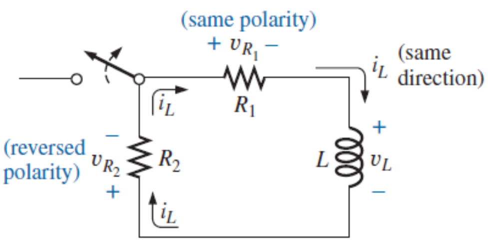


FIG. 43
Network in Fig. 42 the instant the switch is opened.

$$\boxed{v_L = -(v_{R_1} + v_{R_2})}$$

$$\boxed{v_L = -\left(1 + \frac{R_2}{R_1}\right)E}$$

- As an inductor releases its stored energy, the voltage across the coil decays to zero in the following manner:

$$\boxed{v_L = -V_i e^{-t/\tau'}}$$

$$\tau' = \frac{L}{R_T} = \frac{L}{R_1 + R_2}$$

$$\boxed{i_L = \frac{E}{R_1} e^{-t/\tau'}}$$

$$\boxed{v_{R_2} = -\frac{R_2}{R_1} E e^{-t/\tau'}}$$

$$\boxed{v_{R_1} = E e^{-t/\tau'}}$$

R-L TRANSIENTS: THE RELEASE PHASE (contd.)

- if the switch is opened before i_L reaches its maximum value, the equation for the decaying current must change to

$$\boxed{i_L = I_i e^{-t/\tau'}}$$

$$\boxed{v_L = -V_i e^{-t/\tau'}}$$

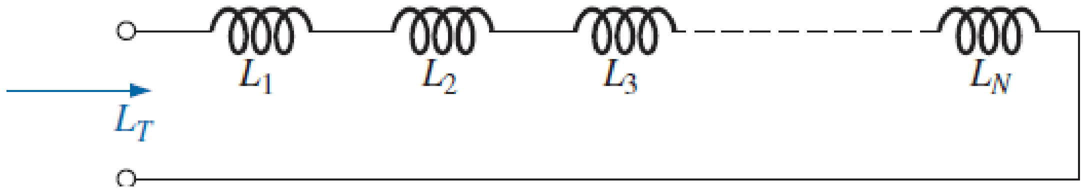
with $$V_i = I_i(R_1 + R_2)$$

THÉVENIN EQUIVALENT: $\tau = L/R_{Th}$

- **Examples (from Boylestad book)**

$$\boxed{v_{L_{av}} = L\frac{\Delta i_L}{\Delta t}} \qquad \text{(volts, V)}$$

INDUCTORS IN SERIES

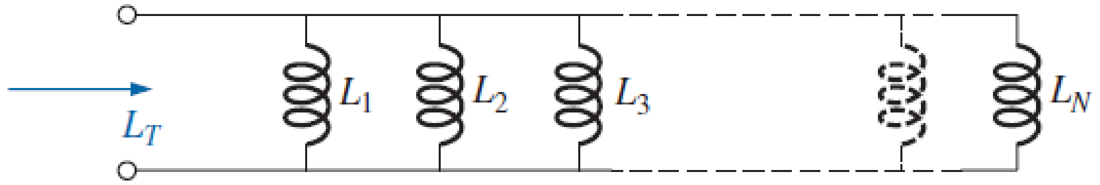


- For inductors in series, the total inductance is found in the same manner as the total resistance of resistors in series

$$\boxed{L_T = L_1 + L_2 + L_3 + \cdots + L_N}$$

INDUCTORS IN PARALLEL

- For inductors in parallel, the total inductance is found in the same manner as the total resistance of resistors in parallel



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

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