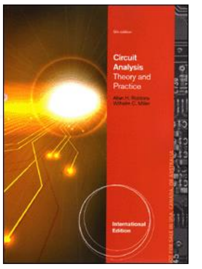
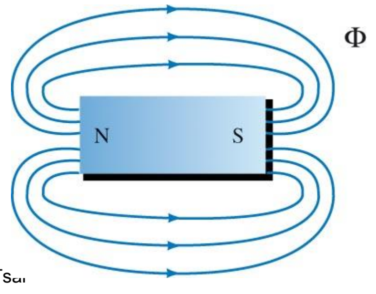


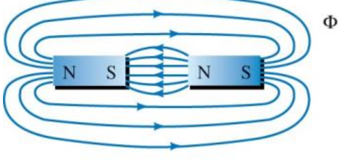
Chapter 12

Magnetism and Magnetic Circuits

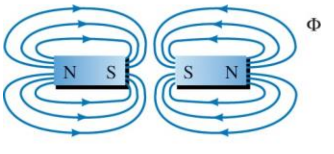
The Nature of a Magnetic Field

- Magnetism
  - Force of attraction or repulsion that acts between magnets and other magnetic materials
- Flux lines
  - Show direction and intensity of this field at all points
- **Field is strongest at poles**
  - **Direction is from N to S**





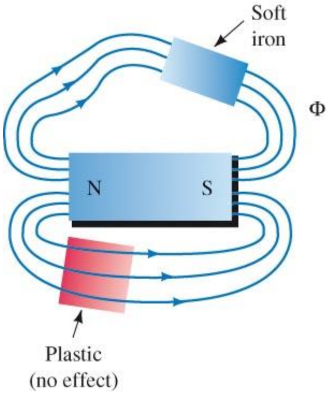
(a) Attraction



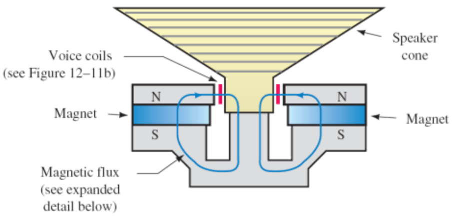
(b) Repulsion

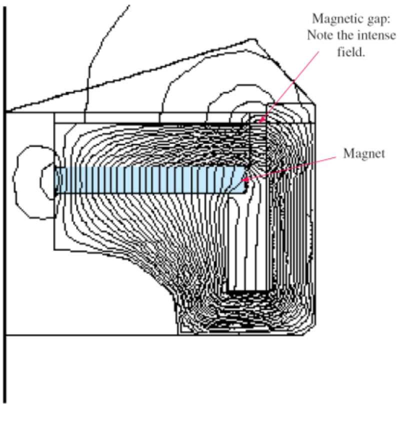
Ferromagnetic Materials

- Attracted by magnets
  - Provide an easy path for magnetic flux
  - **Iron, nickel, cobalt, and their alloys**
- Nonmagnetic materials such as **plastic, wood, and glass**
  - Have no effect on the field



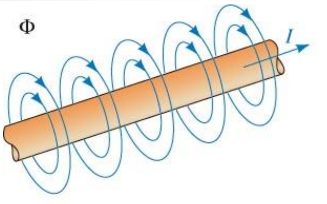
Application: Loudspeaker



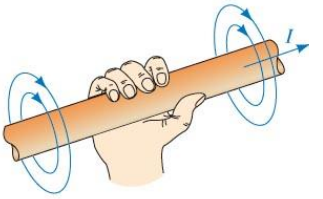


Electromagnetism

- Many applications of magnetism involve magnetic effects due to electric currents
- Direction of magnetic field may be determined by the **Right Hand Rule**
- Place your right hand around conductor with **your thumb** in the direction of the **current**
- **Your fingers** will point in the direction of the **magnetic field**



(a) Magnetic field produced by current. Field is proportional to *I*.

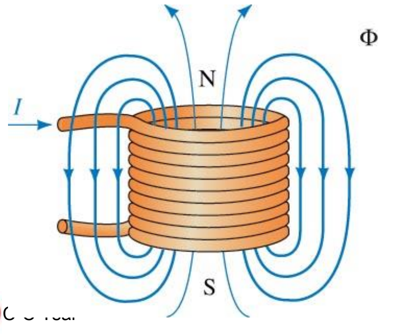


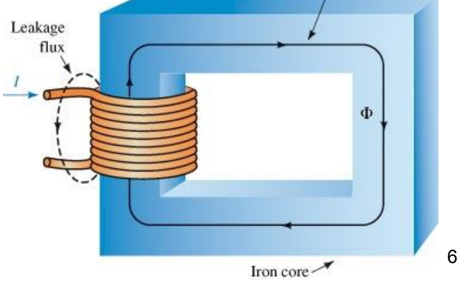
(b) Right-hand rule

Electromagnetism

Rules for coils

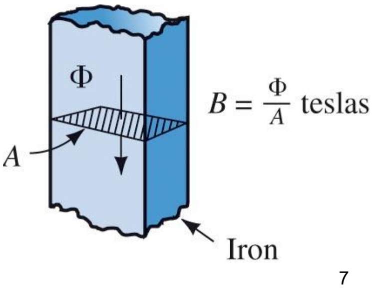
- **Curl fingers** of right hand around coil in direction of the **current**
- **Thumb** will point in direction of the **field**





Magnetic Flux and Flux Density

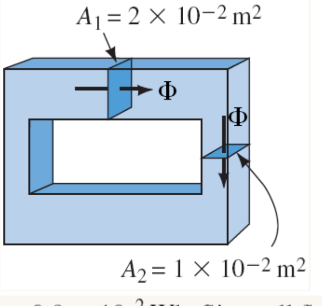
- Flux, Φ : Total number of lines
- **Flux density, $B = \Phi / A$**, : Number of lines per unit area
- Units for magnetic flux are webers (Wb)
- Area is measured in square meters
- Units for flux density
  - Wb/m^2 or teslas (T)
  - 1 tesla = 10 000 gauss
- B may also be measured in gauss
- We will work only with teslas



Example: Magnetic Flux and Flux Density

- Given the flux density at cross section 1 is B_1 = 0.4T, determine B_2

$\boldsymbol{\Phi = B_1 \times A_1} = B_2 \times A_2$

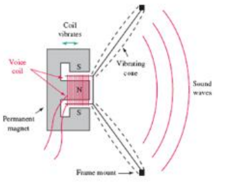


Solution $\Phi = B_1 \times A_1 = (0.4\,T)(2 \times 10^{-2}\,m^2) = 0.8 \times 10^{-2}$ Wb. Since all flux is confined to the core, the flux at cross section 2 is the same as at cross section 1. Therefore,

$$B_2 = \Phi/A_2 = (0.8 \times 10^{-2}\,Wb)/(1 \times 10^{-2}\,m^2) = 0.8\,T$$

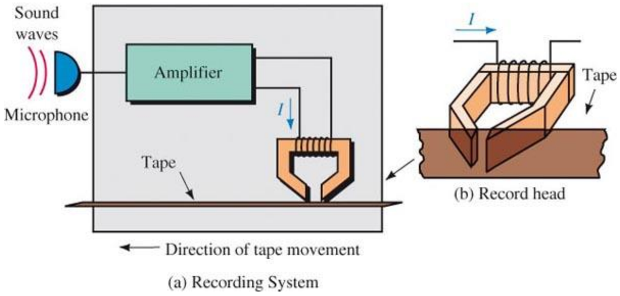
Magnetic Circuits

- Found in **motors**, **generators**, **speakers**, **transformers**
- Magnetic fields can be created by electric currents and permanent magnets
- Magnetic stripe containing information
  - Used in bank ATM cards, library cards, etc.
  - Magnetic patterns encode information
  - Reader sees varying magnetic field
    - Induces a voltage in the pickup winding
    - Voltage is amplified and sent to decoding circuitry
- MRI machine uses superconductor coils
  - Create intense magnetic field



Applications of Magnetic Circuits

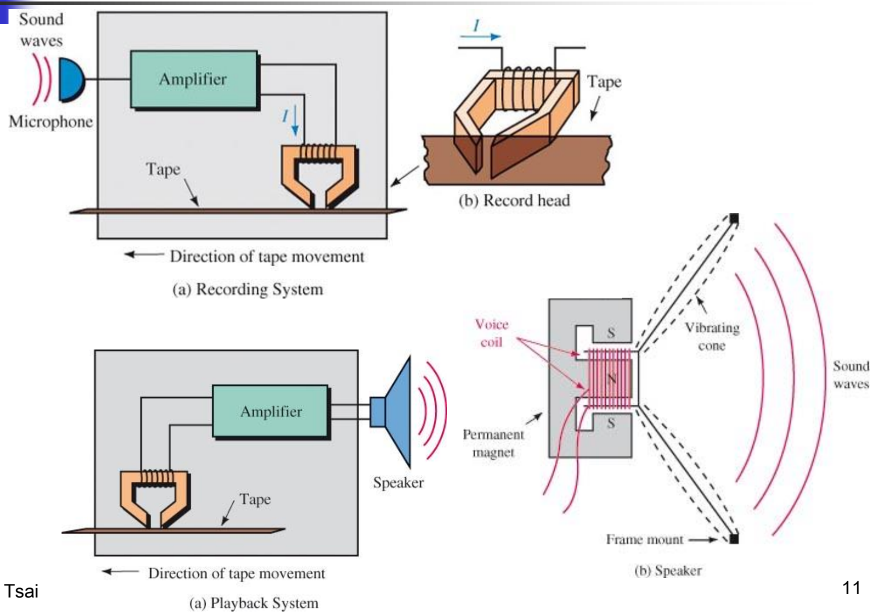
- Practical applications
  - Use structures to guide and shape magnetic flux
  - Called magnetic circuits
- Magnetic circuit guides flux to an air gap
  - This provides field for the voice coil
- Playback heads on **tape recorders**
  - VCRs and disk drives pick up the varying magnetic field and convert it to voltage



(b) Record head

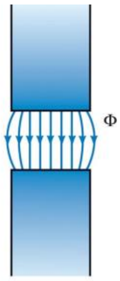
(a) Recording System

Applications of Magnetic Circuits

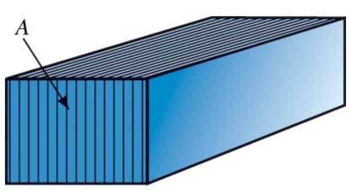


Air Gaps, Fringing, and Laminated Cores

- Magnetic Circuits have air gaps essential to their operation
- Increase each cross-sectional dimension of gap by the size of the gap
- Laminated cores are created with thin sheets of stacked irons or steels
- Stacking factor is used to determine core's effective area



(a) Fringing at gap

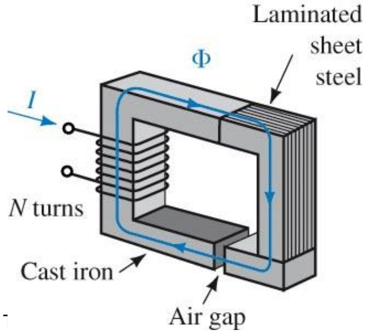


(b) Laminated section. Effective magnetic area is less than the physical area.

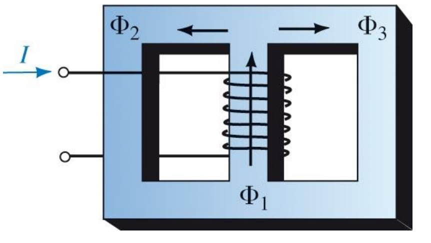
Series Elements and Parallel Elements

- Magnetic circuits may have sections of different materials
  - Cast iron, sheet steel, and an air gap
- For this circuit, flux is the same in all sections
  - Circuit is a series magnetic circuit

Series magnetic circuit



Parallel magnetic circuit



Magnetic Circuits with DC Excitation

- Two basic problems
  - Determine current required to produce a given flux
  - Compute flux produced by a given current

MMF: The Source of Magnetic Flux

- Current through a coil creates magnetic flux
  - The greater the current or number of turns, the greater the flux
- **Magnetomotive force** (mmf)
  - Measured in ampere-turns
  - Denoted by the symbol $\mathscr{F}$

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

C-C Tsai

Reluctance $\Re$: Opposition to Magnetic Flux

- Opposition that circuit presents to flux

$$\Re = \frac{\ell}{\mu A} \quad \text{(At/Wb)}$$

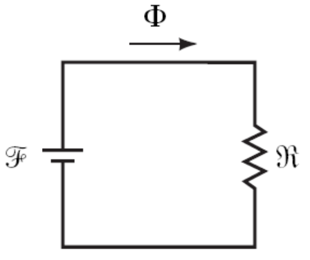
where μ=material permeability

- Permeability measures ease of establishing magnetic flux in a material
  - Ferromagnetic materials have high permeability
  - Nonmagnetic materials have low permeability

C-C Tsai

Ohm's Law for Magnetic Circuits

- Flux does not flow like current



$$\Phi = \mathscr{F}/\mathfrak{R} \quad \text{(Wb)}$$

Magnetic Field Intensity

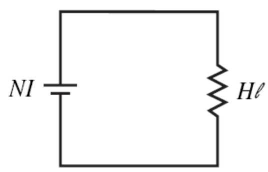
- Magnetic field intensity, *H*
  - Also called magnetizing force
  - Measures mmf per unit length of a circuit

$$H = \mathscr{F}/\ell = NI/\ell \quad \text{(At/m)}$$

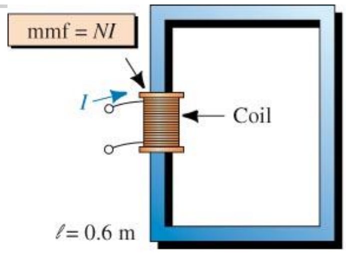
$$NI = H\ell \quad \text{(At)}$$

Magnetic Field Intensity

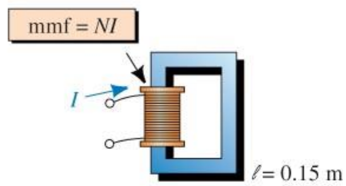
- Magnetic field intensity, H, is the **magnetomotive force (mmf)** per unit length
- $H = \Im/\ell = NI/\ell$ (Ampere•turns/meter)
  - NI is an mmf source
  - $H\ell$ is an mmf drop



$NI = H\ell$



(a) A long path

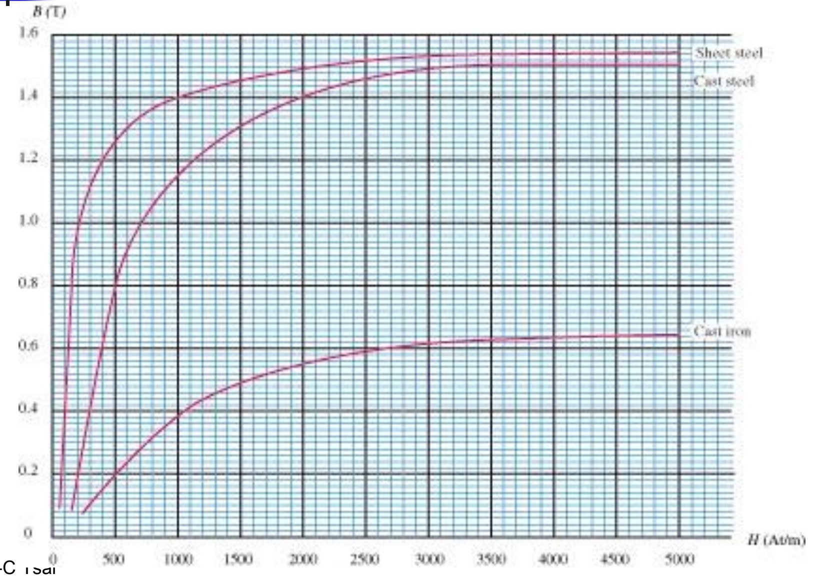


(b) A short path

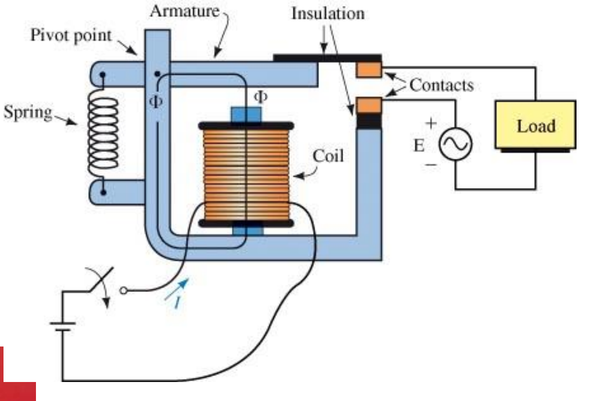
Relationship Between B and H

- B and H
  - Related by the equation $\boldsymbol{B = \mu H}$
    - Where μ (Greek letter mu) is the permeability of the core
- Permeability
  - Measure for establishing flux in a material
- The larger the value of μ
  - The larger flux density for a given H
- H is proportional to I
  - The larger the value of μ, the larger the flux density for a given circuit

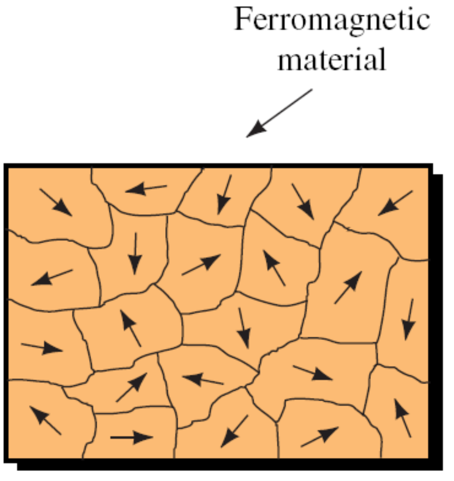
Relationship Between *B* and *H*



Magnetic Applications

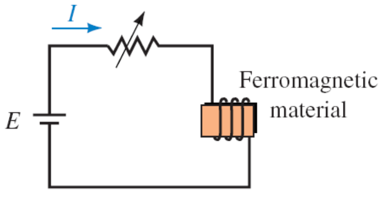


Properties of Magnetic Materials

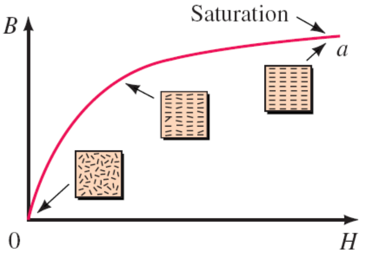


Magnetization Process

- Saturation: All domain fields line up and cannot magnetize it much further



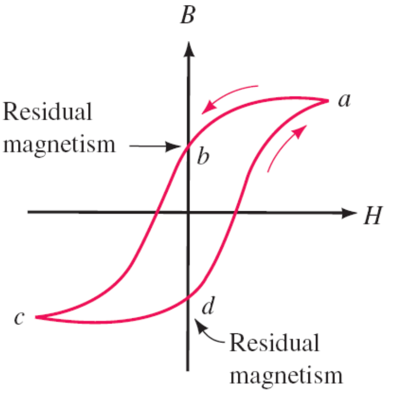
(a) The magnetizing circuit



(b) Progressive change in the domain orientations as the field is increased. *H* is proportional to current *I*.

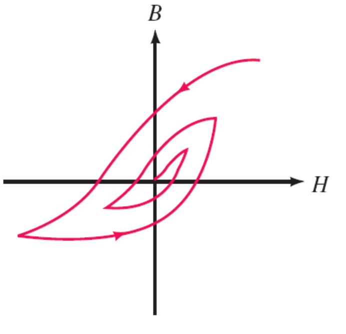
Hysteresis

- Reduce current to zero
  - Specimen retains some magnetism
    - Residual magnetism



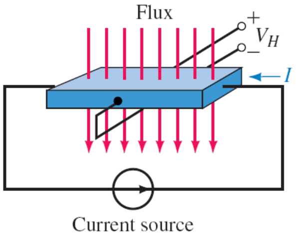
The Demagnetization Process

- Must decrease hysteresis loop to zero
  - Place specimen inside a coil driven by a variable ac sourc
    - Gradually decrease coil current to zero



Measuring Magnetic Fields

- **Hall effect**: Voltage proportional to field strength *B*



- Hall effect gaussmeters use this principle