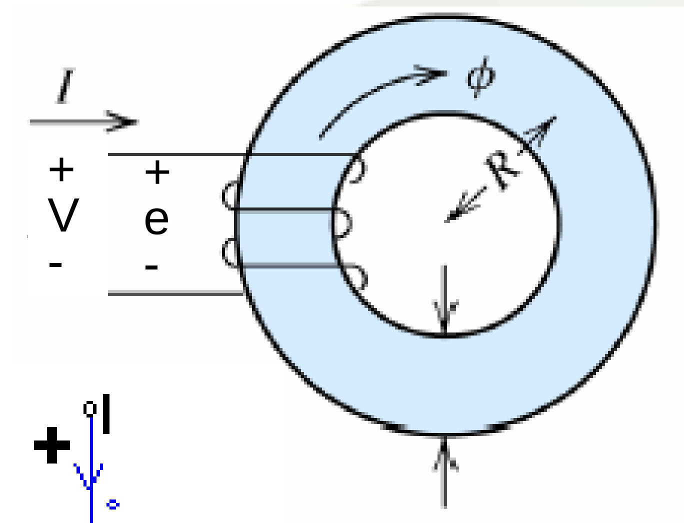
Energy conversion I

Lecture 4:

Topic 1: Magnetic materials and Circuits (S. Chapman, ch. 1)

- Magnetic Field production and Mag. Circuits modeling
- Ferromagnetic Materials behavior
- Faraday’s law
- **Electrical Equivalent Cct. For magnetic Ccts**
- **Permanent Magnet Materials**
- **Force applied on a wire by external magnetic field**
- **Voltage induced in on moving conductor in magnetic field**

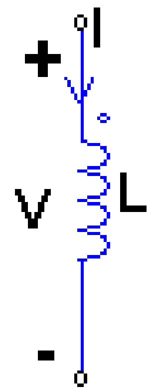
Electrical Equivalent Circuit For magnetic Circuits



Neglecting winding resistance:

$$V = e = \frac{d\lambda}{dt}$$

$\lambda = Li$ **L**: Inductance (Henry)



Neglecting Flux leakage:

$$V = e = \frac{d\lambda}{dt} = \frac{d(Li)}{dt} = L\frac{di}{dt} + i\frac{dL}{dt}$$

$$V = L\frac{di}{dt} \quad !$$

$$\lambda = N\phi = NBA = N\mu HA$$

$$= N\mu\frac{NI}{L_c}A = LI$$

$$\Rightarrow \quad L = \mu\frac{N^2}{L_c}A = \frac{N^2}{R_M}$$

Electrical Equivalent Circuit For magnetic Circuits

Modelling leakage flux:

$$\phi = \phi_l + \phi_M$$

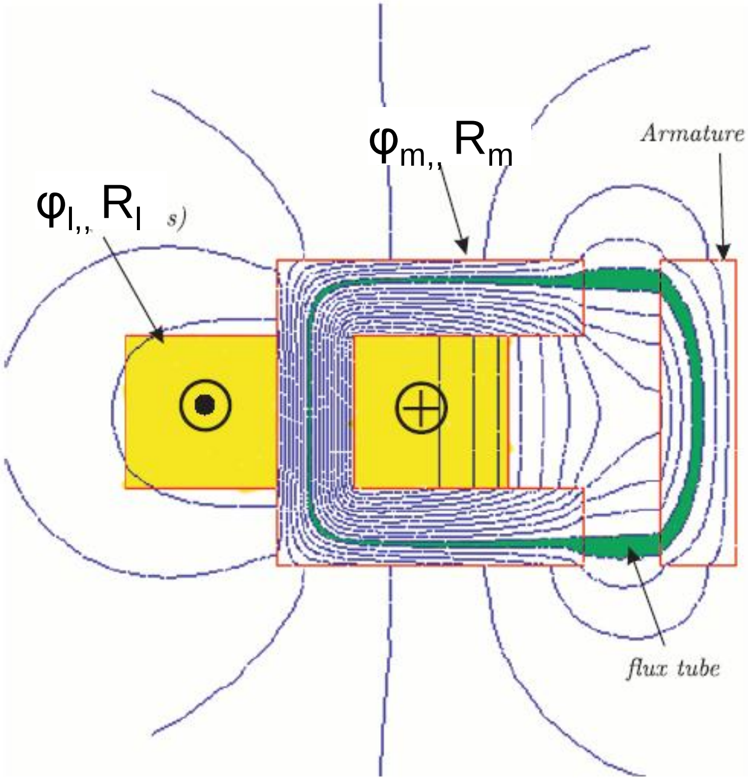
$$\lambda = N\phi = N\phi_l + N\phi_M$$

$$= N\mu_0 \frac{NI}{l_l} A_l + N\mu \frac{NI}{l_M} A_M$$

$$= \frac{N^2}{\frac{l_l}{\mu_0 A_l}} I + \frac{N^2}{\frac{l_M}{\mu A_M}} I = (L_l + L_M) I$$

$$L_{eq} = L_l + L_M$$

Series Inductances



Note:

$$\phi = \phi_l + \phi_M$$

$$= \frac{NI}{R_l} + \frac{NI}{R_M} = NI\left(\frac{1}{R_l} + \frac{1}{R_M}\right)$$

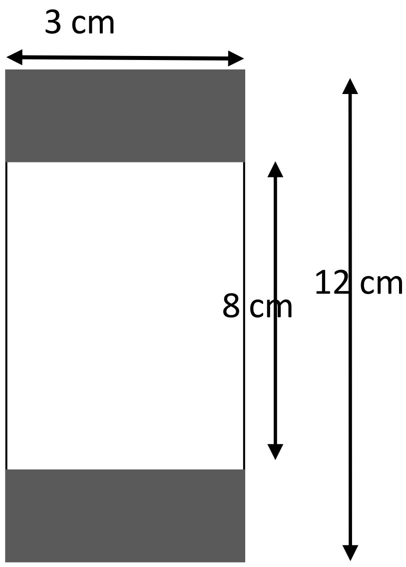
$$= \frac{F}{R_{eq}} \Rightarrow \frac{1}{R_{eq}} = \frac{1}{R_l} + \frac{1}{R_M}$$

Parallel reluctances

What about winding resistance

Example:

Following figure shows the cross section of a 100 turns iron core coil. For B<1 T, μ = 0.01
The wire resistance is 10 Ω.
A- what is the maximum current if the core is not saturated.
B- What is the maximum magnitude (rms) of a simusoidal 50 Hz Voltage if the core is not saturated.



Solution:

A:

$$H.l_c = Ni \quad \Rightarrow i = \frac{H.l_c}{N} = \frac{\frac{1}{0.01} \times 0.1\pi}{100} 0.314 \ \text{A}$$

B: The equivalent circuit is an R-L:

$$L = \frac{N^2}{R_m} = \frac{N^2}{\frac{l_c}{\mu A_c}} = \frac{100^2}{\frac{0.1\pi}{0.01(0.03 \times 0.02)}} = 0.191 \ \text{H}$$

$$V_{max} = (R + j\omega L) I_{max}$$

$$I_{max} = \frac{0.314}{\sqrt{2}} = 0.222 \ \text{A}$$

$$|V_{max}| = |(10 + j \times 100\pi \times 0.191)| \times 0.222 = 13.5 \ \text{V}$$

Repeat B for DC voltage!

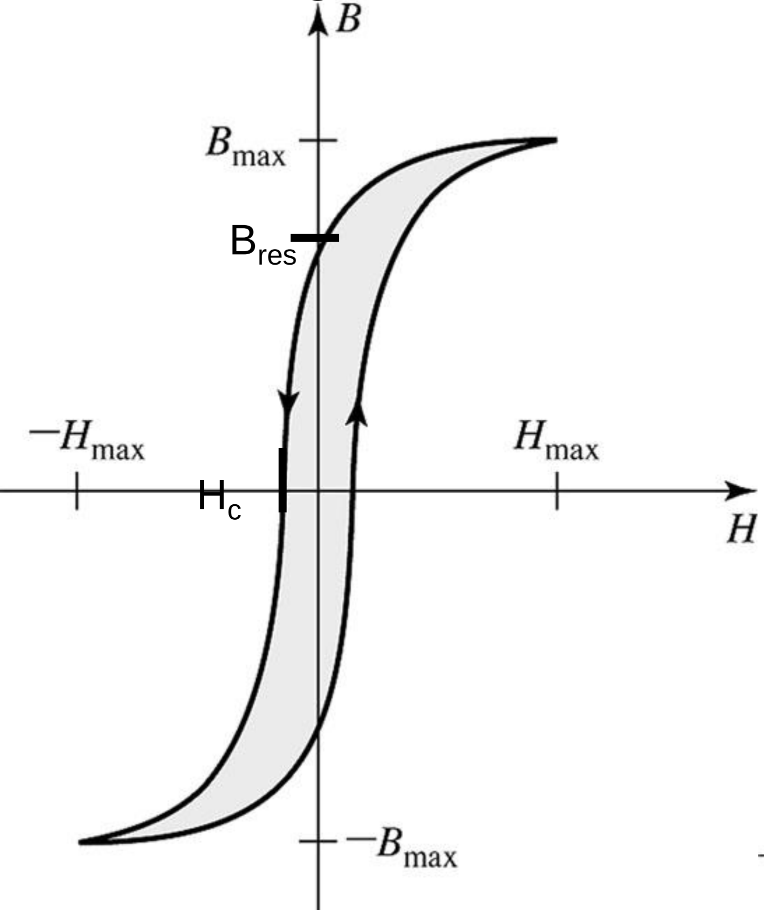
Permanent Magnet Materials

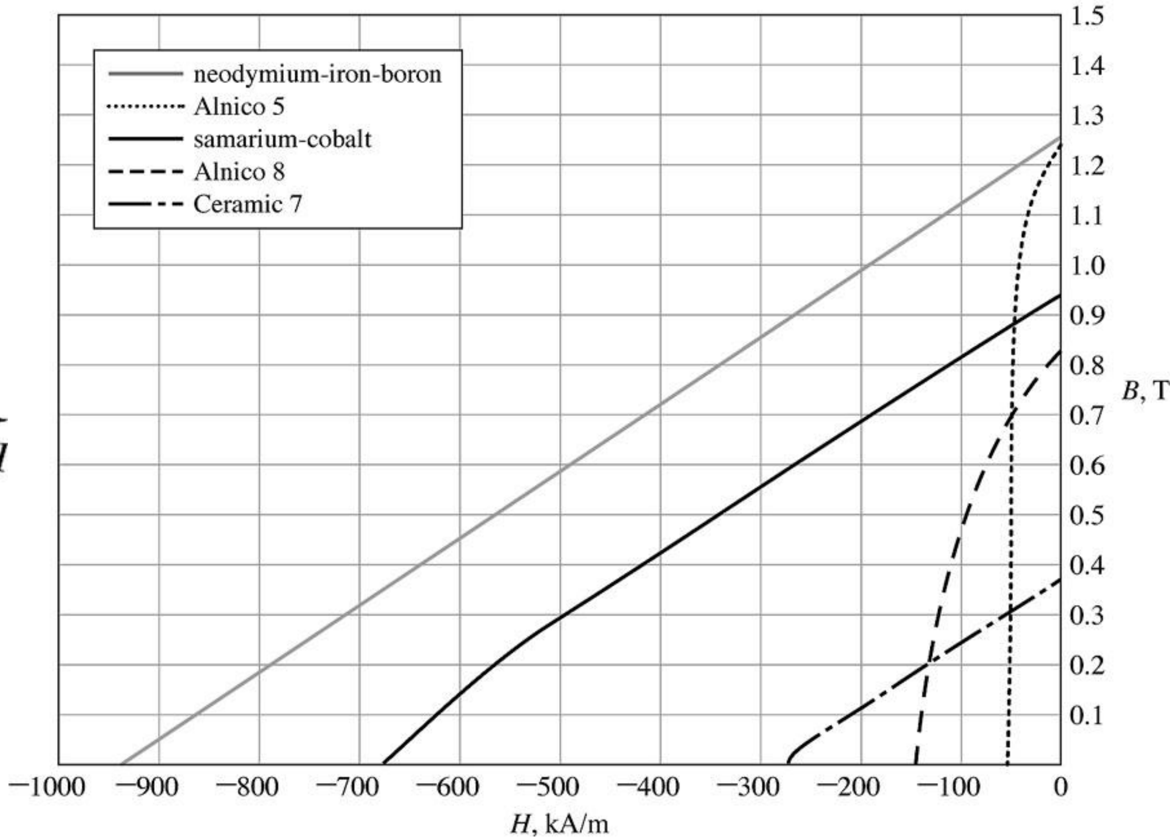
B_{res} : Residual flux generating magnetic flux in the magnetic systems

H_c: Coercive magnetizing intensity (required to demagnetize the core)

Having as large a B_{res} and H_c as possible is better

External magnetic fields and excessive heating can demagnetize PMs





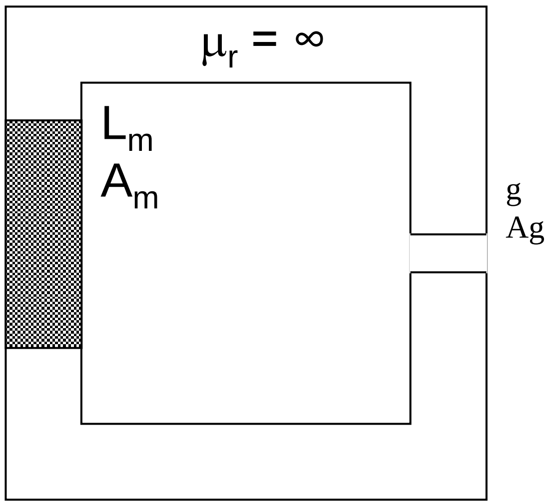
Permanent Magnet Systems

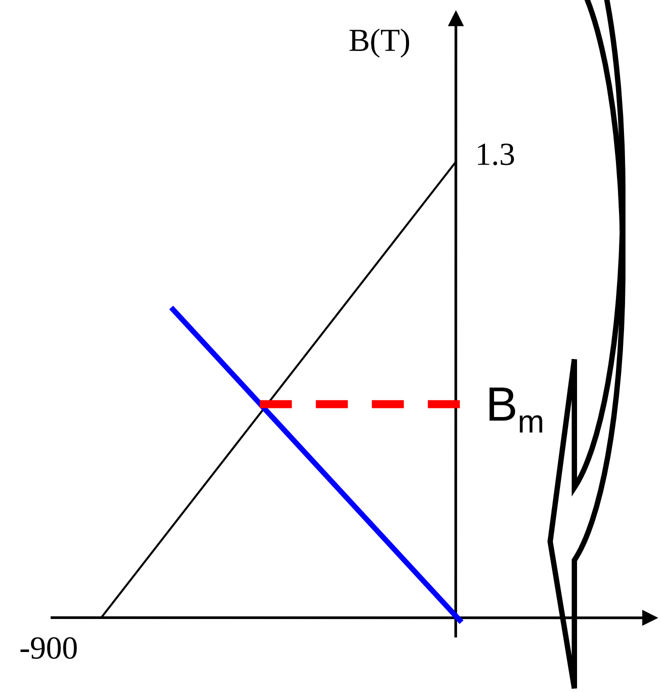
$H_m L_m + H_g g = 0$ (Amp law)

$B_m A_m = B_g A_g = \mu_0 H_g A_g$

$H_g = -H_m L_m / g$

$\boxed{B_m = -\mu 0 A_g H_m L_m / (g \times A_m)}$ & PM





Minimizing PM volume to have a required B (usually B_g)

:

$$V_m = L_m \times A_m = -\frac{H_g g}{H_m} \times \frac{B_g A_g}{B_m} = -\frac{B_g^2 \ V_g}{\mu_0 B_m \times H_m}$$

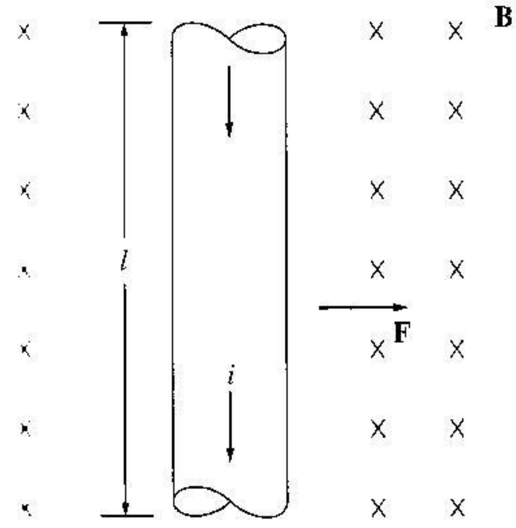
Minimizing PM volume if $B_m \times H_m$ Is maximum

Force applied on a wire by ext. magnetic field

Force will be exerted to a **current carrying conductor** present in a **magnetic field of flux density B**.

$$F = i\,(\mathbf{l} \times \mathbf{B})$$

i: current,
l: length of wire (vector), in direction of current flow
B: Flux density (Vector)

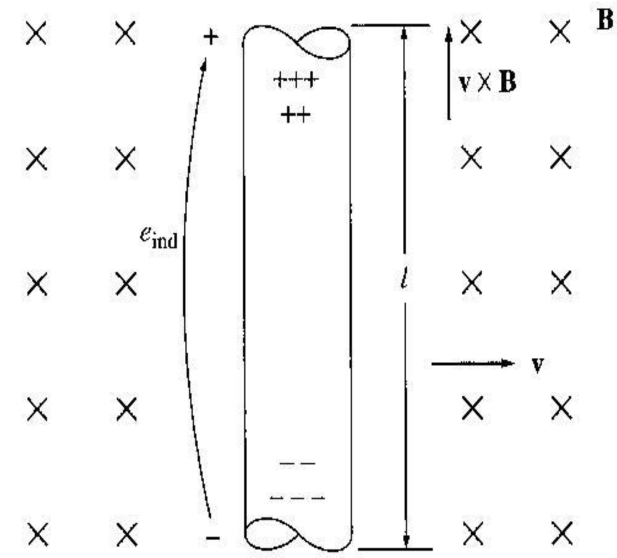


Very **simple** case when **l** is perpendicular to **B:**

$$\mathbf{F=ilB}$$

Voltage induced in on moving conductor in magnetic field

Voltage will be **induced** on the terminals of a **moving** conductor **cutting** a **magnetic field**.



$$e_{ind} = (\mathbf{v} \times \mathbf{B}).\mathbf{l}$$

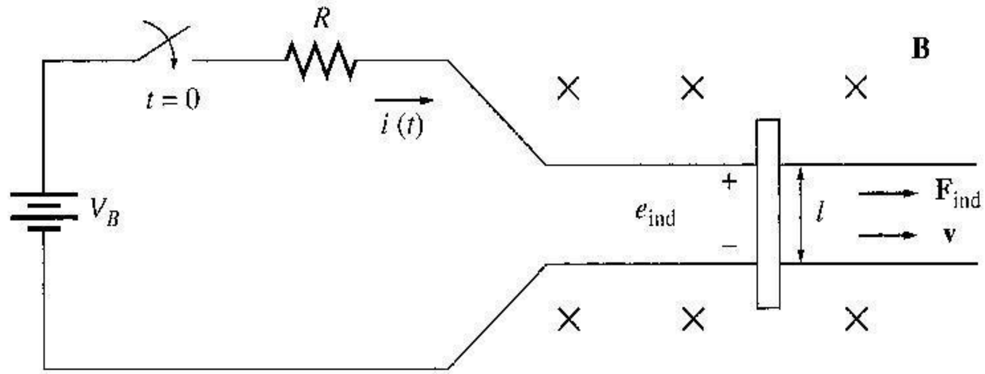
v – velocity of the wire (Vector)
B – magnetic field density (vector)
l – length of the wire in the magnetic field (Vector)

Very simple case when **v** is perpendicular to **B and l:**

$$\mathbf{e_{ind} = vBl}$$

Example: Linear DC motor

Turning on the switch→current→force→ movement→induced volatge



If no-load:

Induced voltage = Applied voltage
Speed = No-load speed

If loaded:

Steady state current to generate required Force (load) $\longrightarrow$ Induced voltage < Applied voltage $\longrightarrow$ Speed < No-load speed

How does no-load speed changes with input voltage variations?
What is the difference between no-load and loaded speed?

Think about Linear DC generator