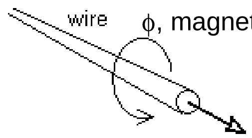
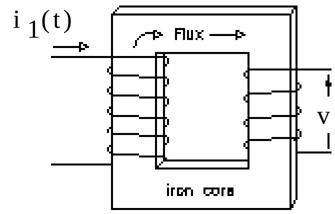
Electromagnetics basics

1. Electric currents produce magnetic fields.



Right-hand-rule

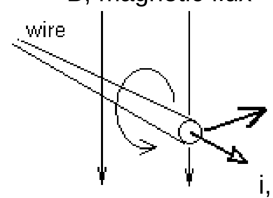
2. A fluctuating magnetic field passing through a coil of wire will induce a voltage in that coil. Basis of transformer secondary, and primary too (back EMF).



$$v_2(t) = N \cdot \frac{d}{dt}\phi$$

3. A wire with a current in the presence of another magnetic field feels a force.

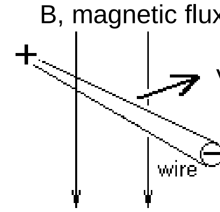
   (Basis of electric motors, also explains why generators resist the mechanical input)



F, force = $i \cdot B \cdot \ell$

ℓ = length of the wire

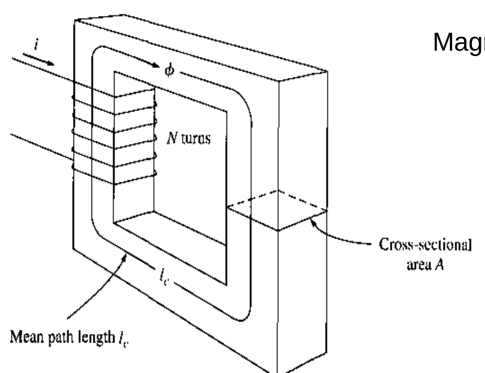
4. A voltage will be induced on wires moving in the presence of a magnetic field. This is very similar to 2. (Basis of electric generators)



1. Magnetic field from a current

Ampere's law: $\oint \mathbf{H} \cdot \mathbf{dl} = I_{net}$

For us...



(Chapman, Fig.1.3)

Magnetic field intensity: $H = \frac{N \cdot i}{\ell_c}$ $\left(\frac{A \cdot turns}{meter}\right)$

Ampere-turns: $= N \cdot i$
(like voltage)

Flux density: $B = \mu \cdot H = \frac{\mu \cdot N \cdot i}{\ell_c}$ (tesla, T)

Flux: $\phi = B \cdot A$ (weber) (Wb)
(like current)

Permeability of free space: $\mu_o := 4 \cdot \pi \cdot 10^{-7} \cdot \frac{henry}{m}$

Relative permeability: μ_r

Permeability: $\mu = \mu_r \cdot \mu_o$

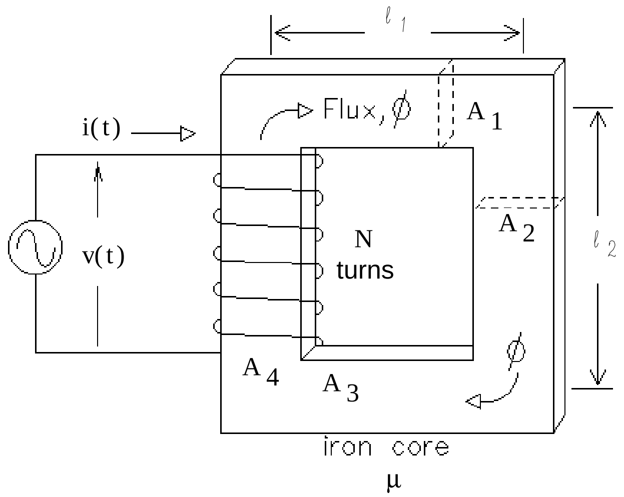
Reluctance of core: $\mathcal{R}_c = \frac{\ell_c}{\mu \cdot A_c}$ $\left(\frac{A \cdot turns}{Wb}\right)$
(like resistance)

Flux: $\phi = \frac{N \cdot i}{\mathcal{R}_c}$ (weber, Wb)

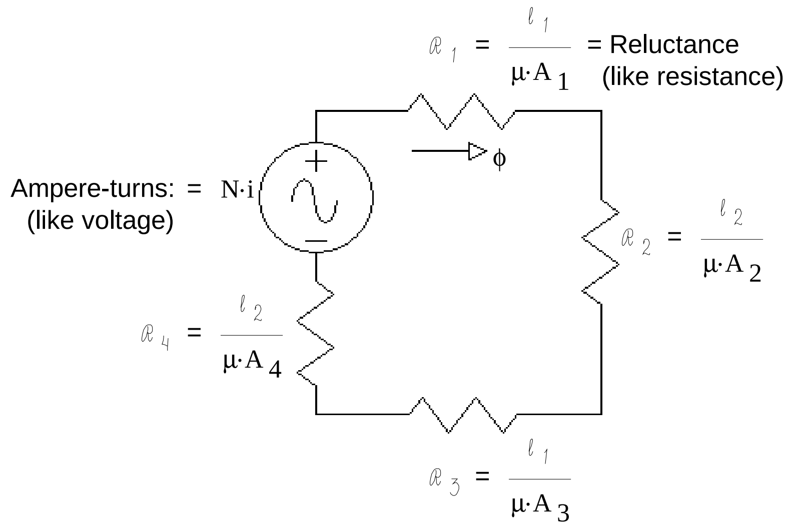
Inductance: $L = \frac{N^2}{\mathcal{R}_c} = N^2 \cdot \left(\frac{\mu_r \cdot \mu_o \cdot A_c}{\ell_c}\right)$ (henry, H)

material	relative permeability μ_r
Mu-metal	20000
Permalloy	8000
Electrical steel	4000
ferrite (nickel zinc)	16 - 640
ferrite (manganese zinc)	>640
Steel	700
Nickel	100

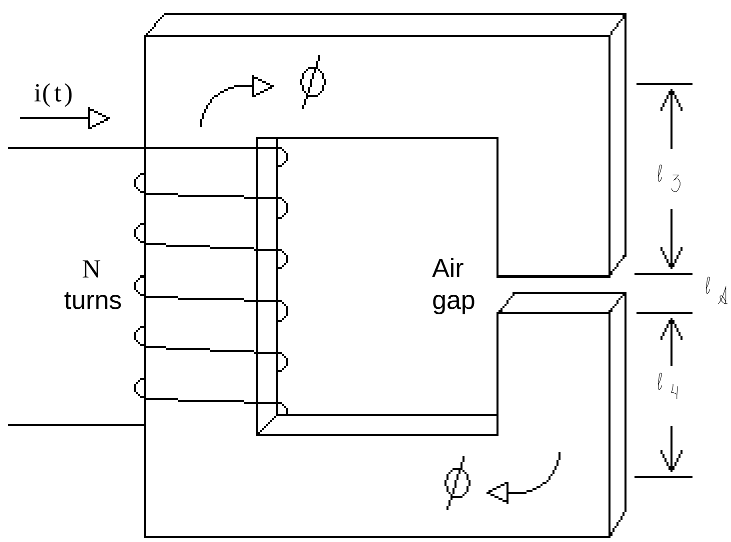
Magnetic "Circuits"

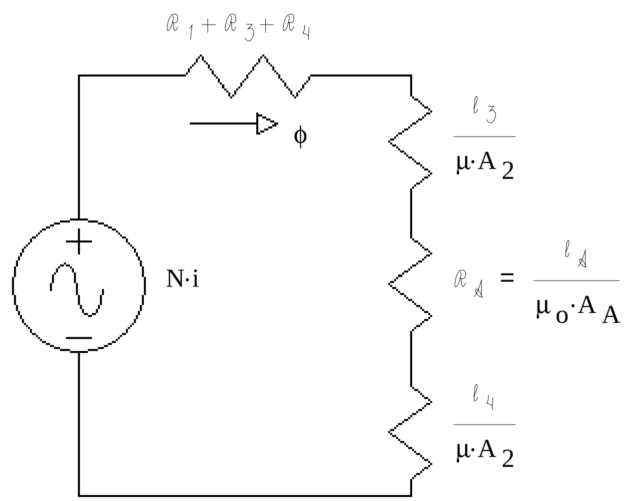


Similar to this electric circuit



magnetic flux = (like current) $\phi = \frac{N \cdot i}{\mathcal{R}_1 + \mathcal{R}_2 + \mathcal{R}_3 + \mathcal{R}_4}$ (weber) (Wb)





$$\phi = \frac{N \cdot i}{\mathcal{R}_1 + \mathcal{R}_3 + \mathcal{R}_4 + \frac{l_3 + l_4}{\mu \cdot A_2} + \mathcal{R}_A}$$ (weber) (Wb)

Flux density: $B = \frac{\phi}{A} = \mu \cdot H$ (tesla, T)

Magnetic field intensity: $H = \frac{B}{\mu} = \frac{\phi}{A \cdot \mu}$ $\left(\frac{A \cdot turns}{meter}\right)$

$$v(t) = N \cdot \frac{d}{dt}\phi = N \cdot \frac{d}{dt} B \cdot A$$

$$= -N \cdot \frac{d}{dt}\phi = -N \cdot \frac{d}{dt} B \cdot A$$ often shown with a negative sign

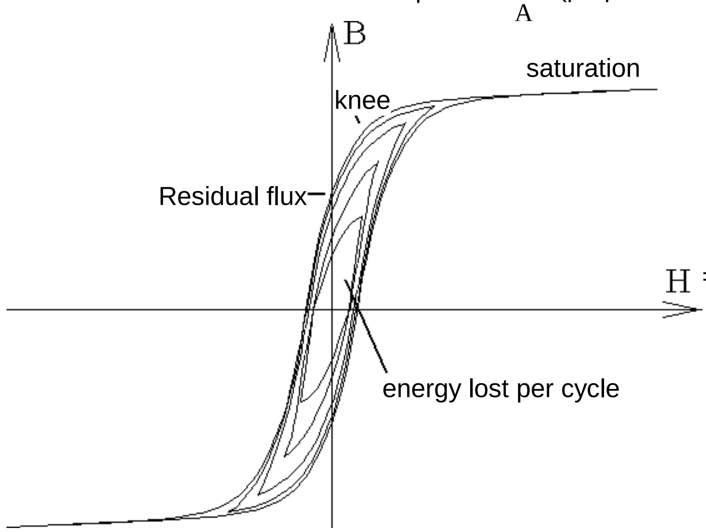
- indicates that this voltage tries to produce a current to oppose the change.

Non-ideal Ferrromagnetic materials (B-H curve)

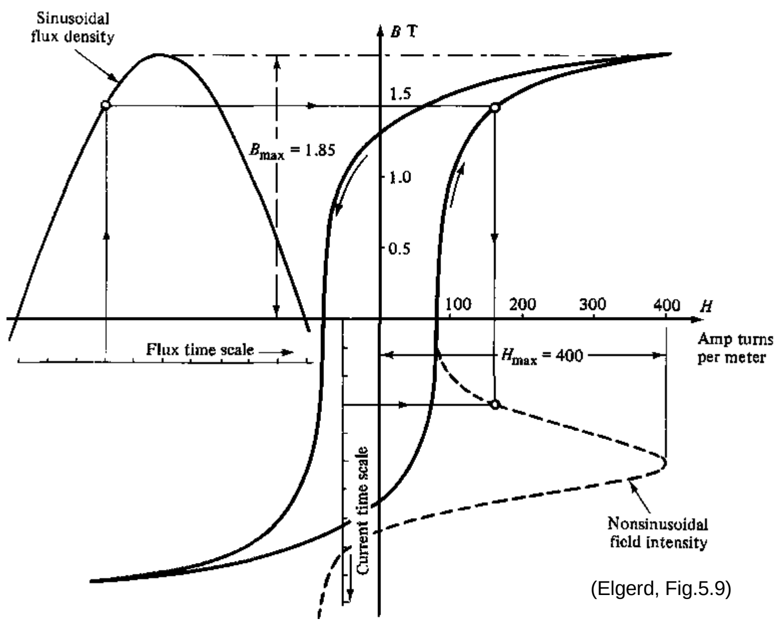
Magnetics are not really linear

The B-H or Hystereses curve

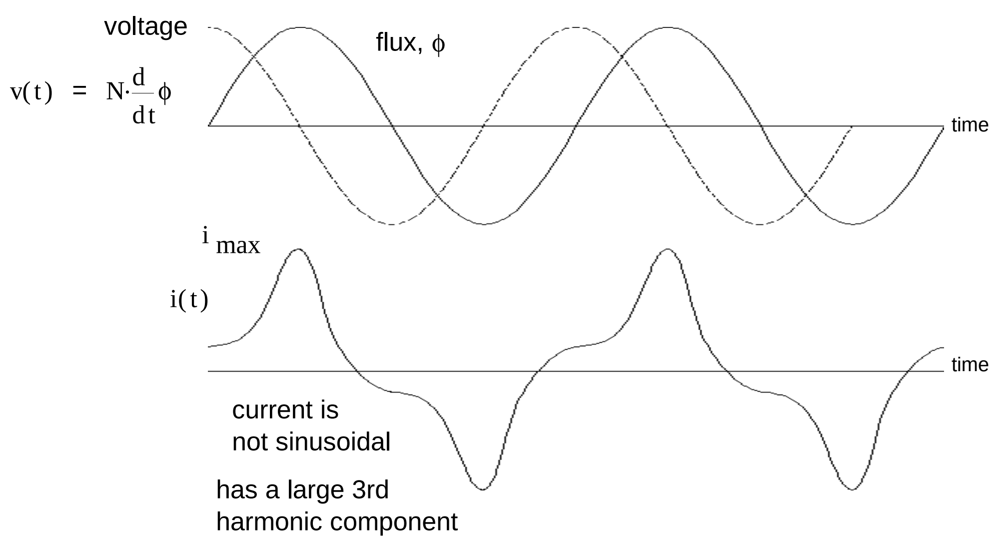
$B = \mu \cdot H = \frac{\phi}{A}$ (proportional to voltage) $v(t) = N \cdot \frac{d}{dt}\phi = N \cdot \frac{d}{dt} B \cdot A$



$H = \frac{N \cdot i}{l_c}$ (proportional to current)



(Elgerd, Fig.5.9)



Sources: Electric Machinery and Power System Fundamentals, Stephen J. Chapman
Basic Electric Power Enineering, Ollie I. Elgerd