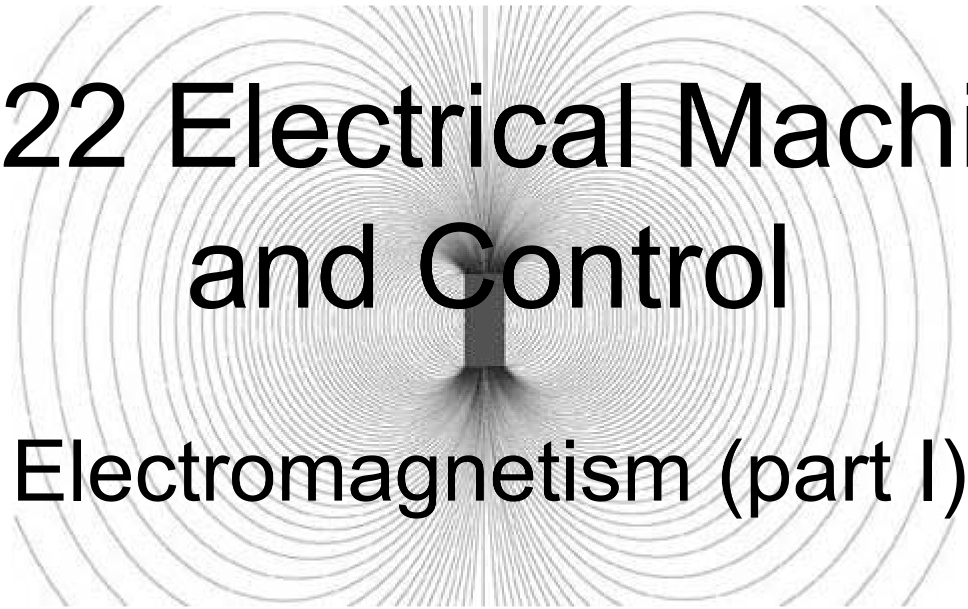


19222 Electrical Machines and Control

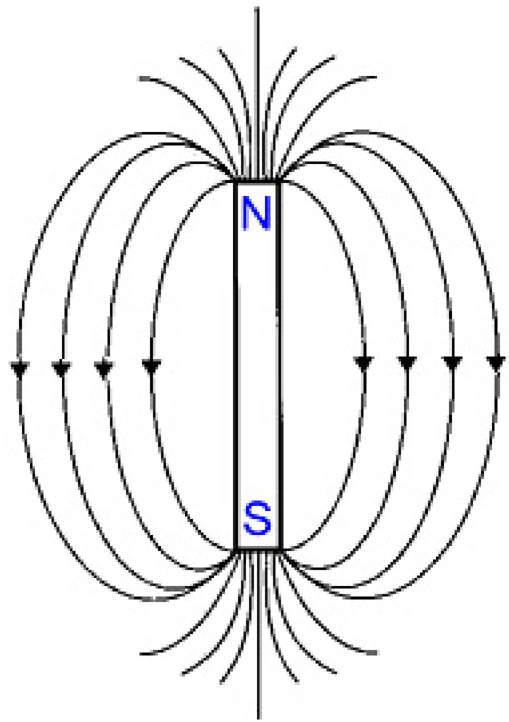
Electromagnetism (part I)

Electromagnetism

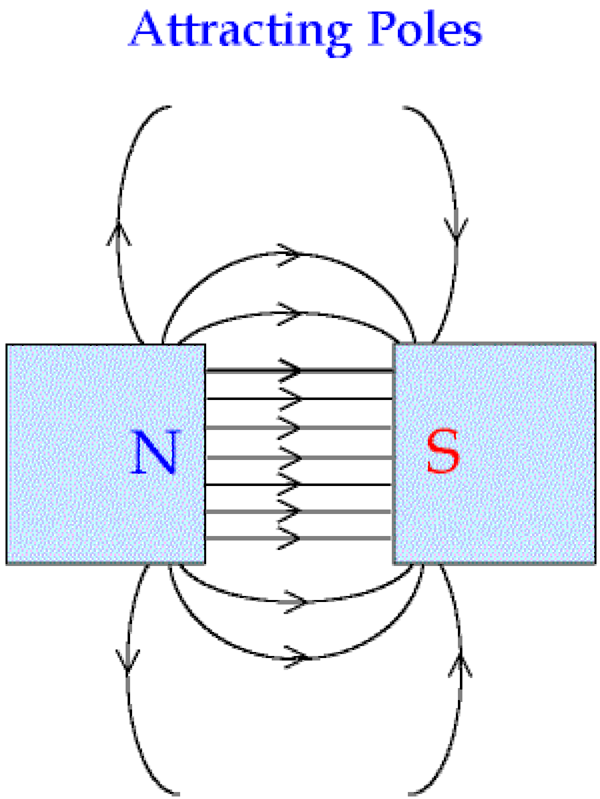
- Aim: impart an understanding of electromagnetic principles
- Important as electromagnetism underpins the operation of many electrical machines
- Linkage between electrical and mechanical worlds

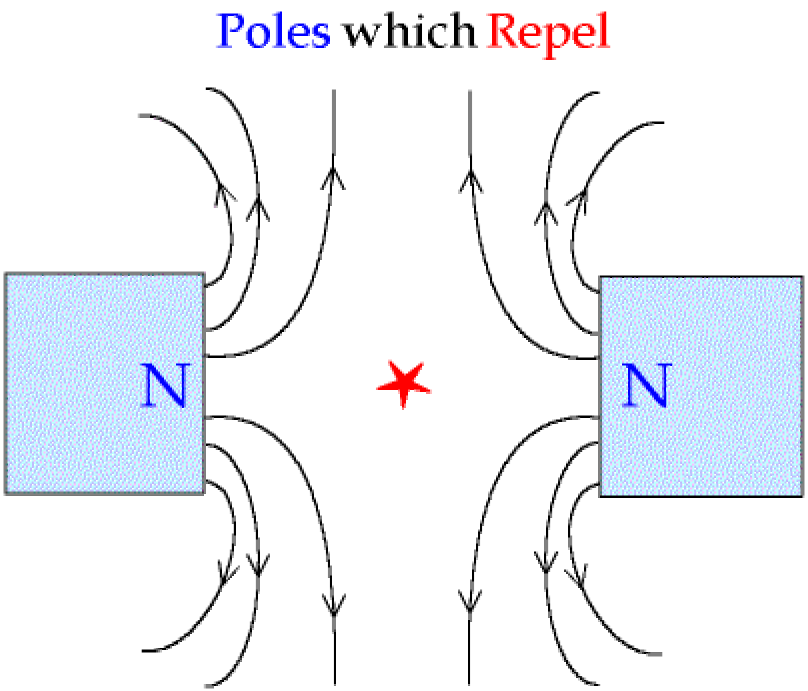
Electromagnetism

- Magnetic field around a bar magnet
- Two “poles” dictated by direction of the field
- Opposite poles attract (aligned magnetic field
- Same poles repel (opposing magnetic field)



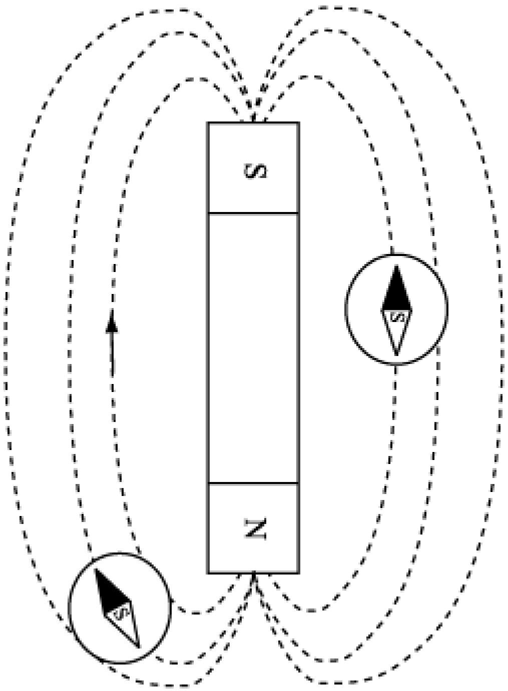
Electromagnetism





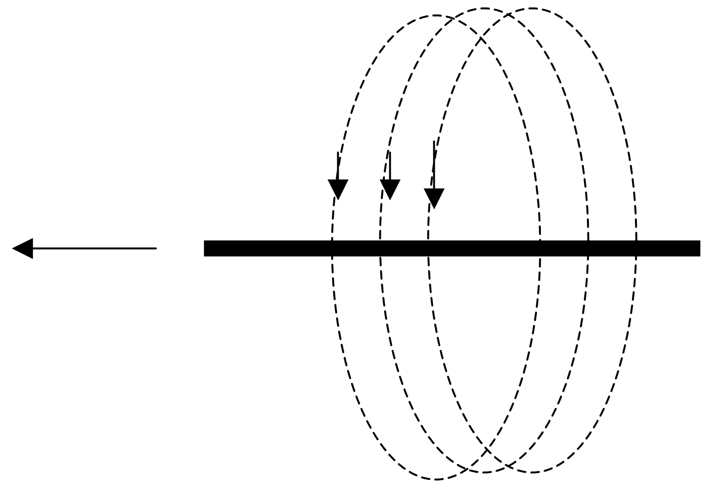
Field Detector

- Can use a compass to map out magnetic field
- Field forms closed “flux lines” around the magnet
- Magnetic flux measured in Webers (Wb)
- Symbol Φ



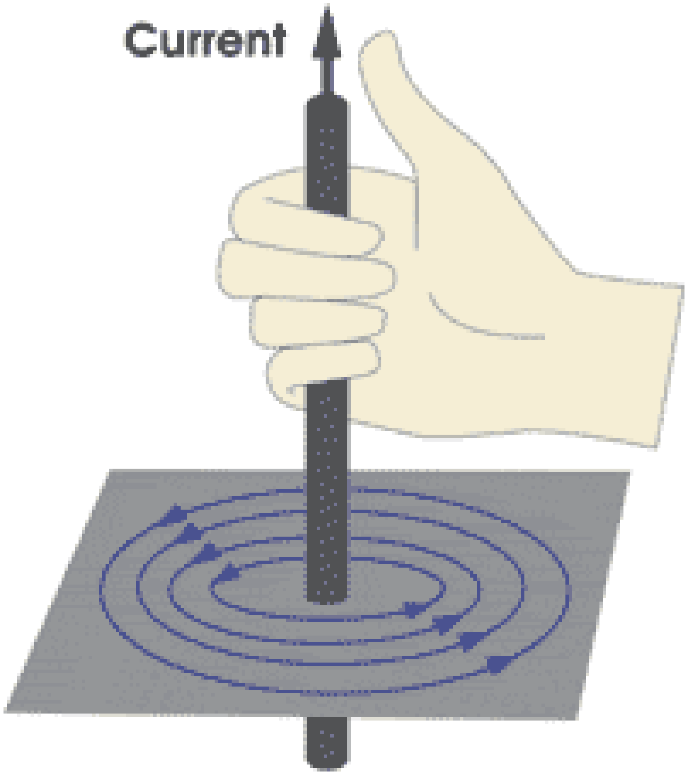
Magnetic Field Conductor

- A magnetic field also forms round a conductor along which a current is flowing
- Field can be described using “right hand screw rule”



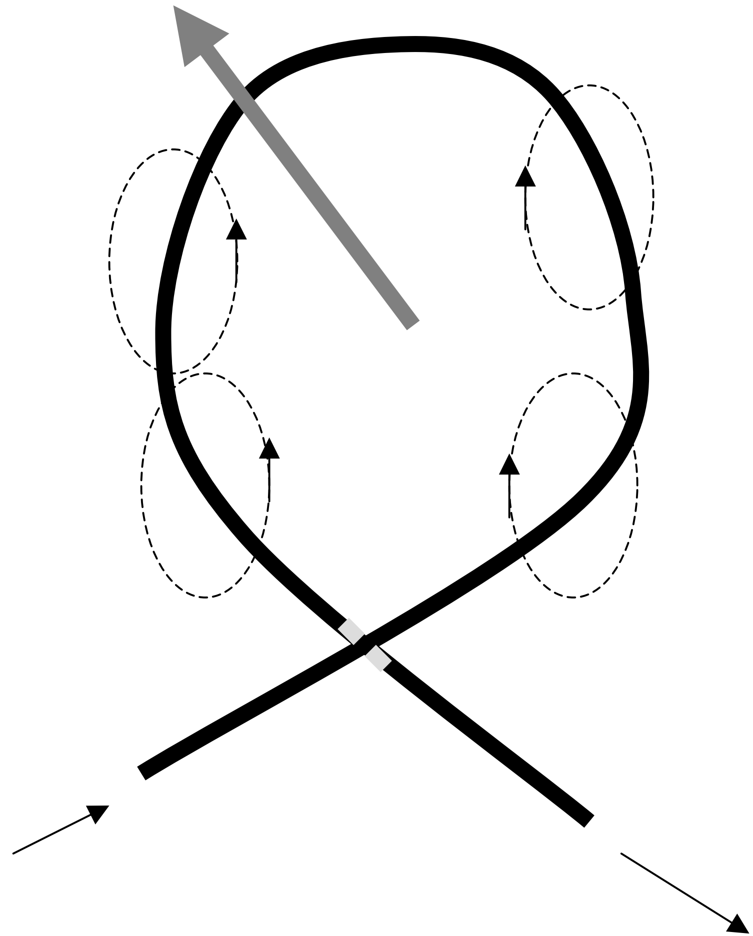
Right Hand Rule

- Thumb indicates direction of current flow
- Finger curl indicates the direction of field



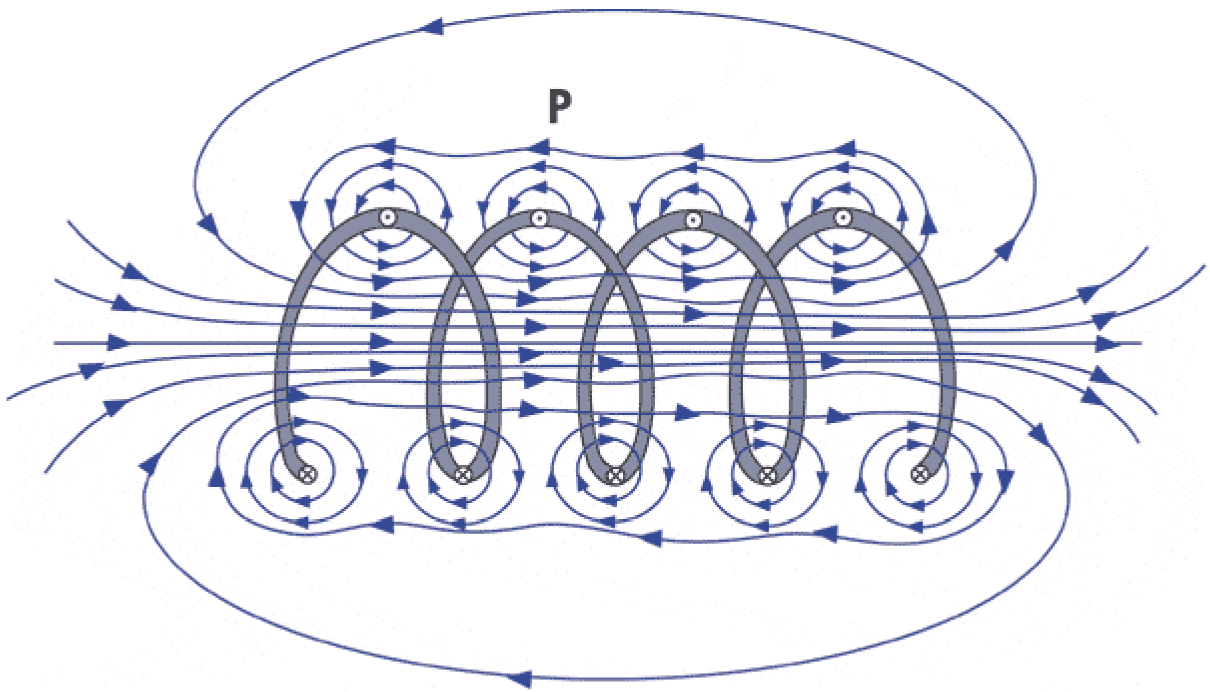
Wire Coil

- Notice that a coil of wire will produce a perpendicular field

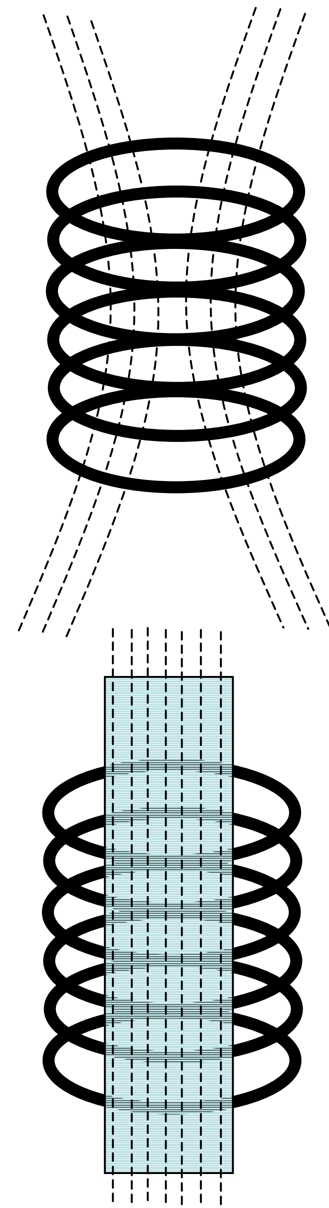


Magnetic field: coil

- A series of coils produces a field similar to a bar magnet – but weaker!



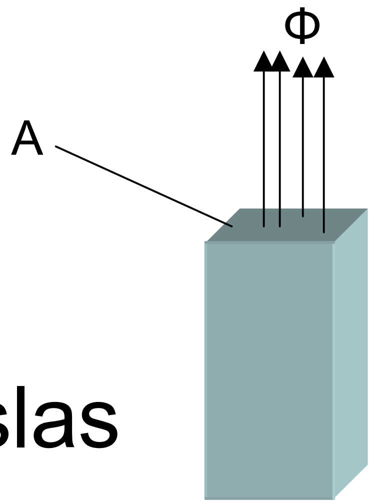
Magnetic field: coil



- Placing a ferrous material inside the coil increases the magnetic field
- Acts to concentrate the field also notice field lines are parallel inside ferrous element
- ‘flux density’ has increased

Flux Density

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

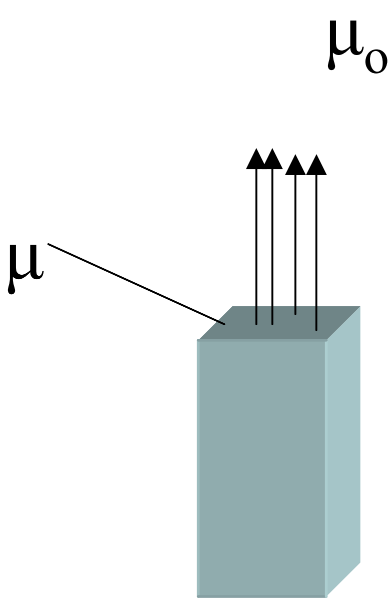


- Flux density measured in Teslas (T)

Permeability

- Permeability **μ** is a measure of the ease by which a magnetic flux can pass through a material (Wb/Am)
- Permeability of free space μ_o = $4\pi \times 10^{-7}$ (Wb/Am)
- Relative permeability:

$$\mu_r = \frac{\mu}{\mu_o}$$

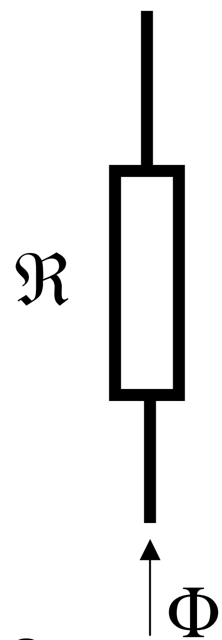


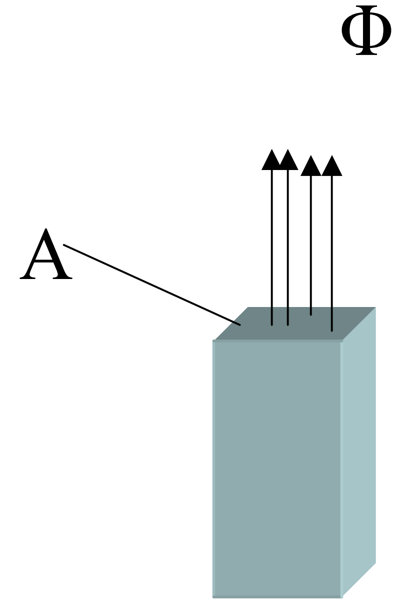
Reluctance

- Reluctance: $\Re$ "resistance" to flow of magnetic flux

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

- Associated with "magnetic circuit" – flux equivalent to current
- What's equivalent of voltage?

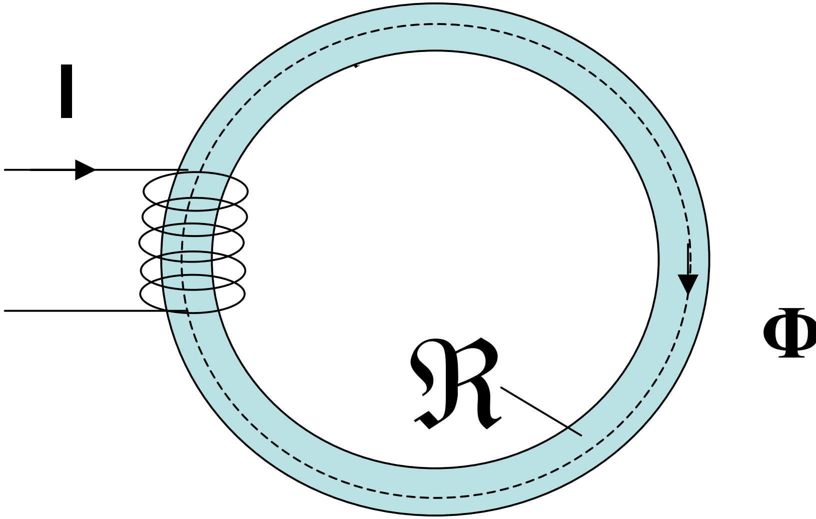




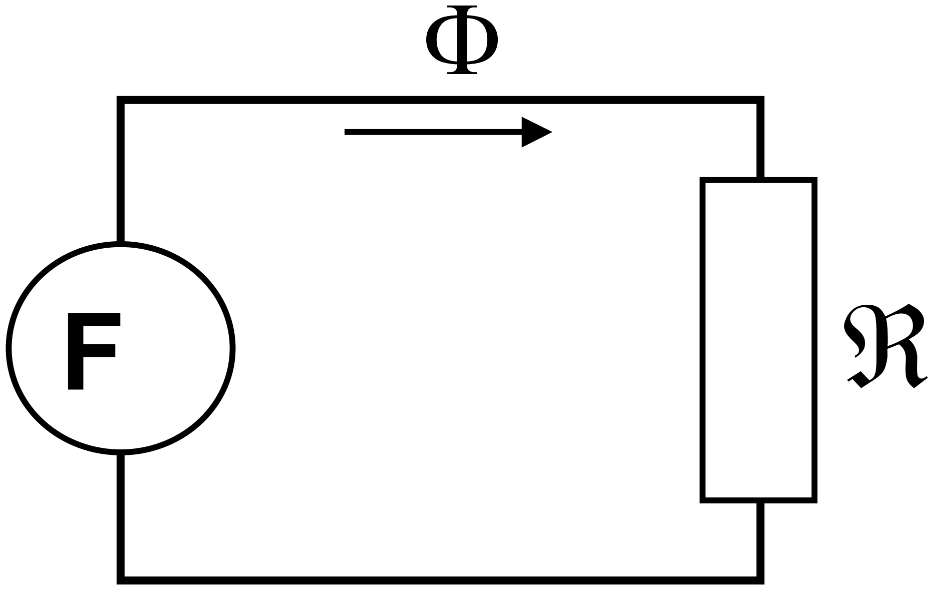
Magnetomotive Force

- Coil generates magnetic field in ferrous torroid
- Driving force **F** needed to overcome torroid reluctance $\Re$
- Magnetic equivalent of ohms law

$$\Phi = \frac{\mathbf{F}}{\Re} \qquad \text{(T)}$$



Circuit Analogy



Magnetomotive Force

- The MMF is generated by the coil
- Strength related to number of turns and current measured in Ampere turns (At)

$$\mathbf{F} = \boldsymbol{NI}$$

$$\Phi = \frac{NI}{\Re}$$

Field Intensity

- The longer the magnetic path the greater the MMF required to drive the flux
- Magnetomotive force per unit length is known as the "magnetizing force" or "field intensity" $\boldsymbol{H}$

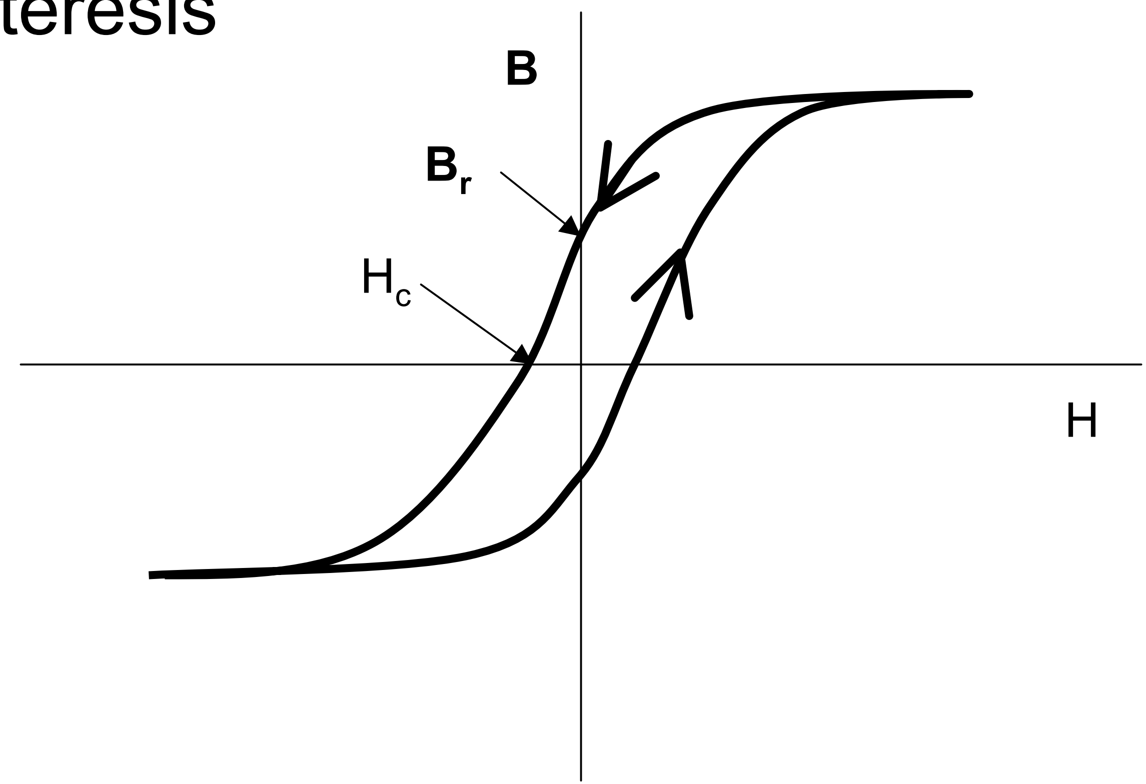
$$H = F / l \text{ (At/m)}$$

- Magnetizing force and flux density related by:

$$\mathbf{B} = \mu H \quad \text{(T)}$$

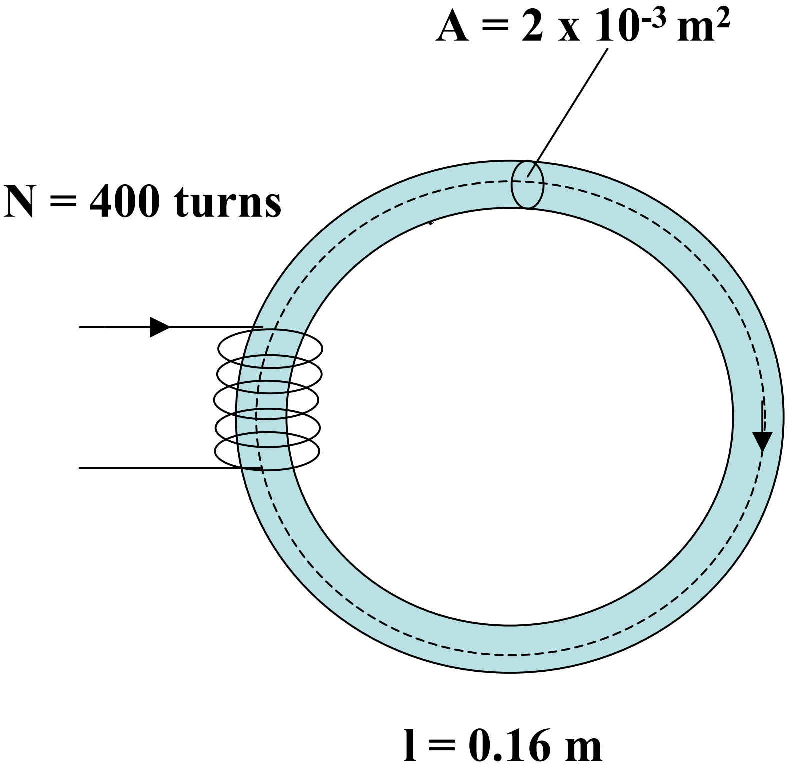
Hysteresis

- The relationship between **B** and ***H*** is complicated by non-linearity and "hysteresis"



Example

- Find the value of *I* needed to develop a magnetic flux of 4 x 10^{-4} Wb
- The permeability of the material is 1.818 x 10^{-3} Wb/Am
- Flux density



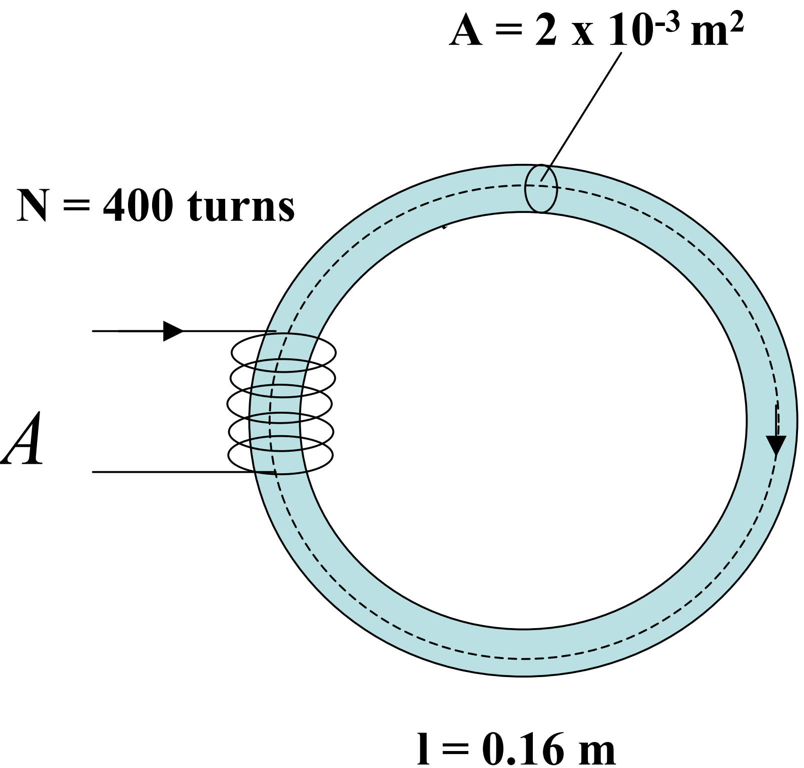
$$B = \frac{\Phi}{A} = \frac{4 \times 10^{-4}}{2 \times 10^{-3}} = 0.2\ T$$

$$H = \frac{B}{\mu} = \frac{0.2}{1.818 \times 10^{-3}} = 110\ At/m$$

Example

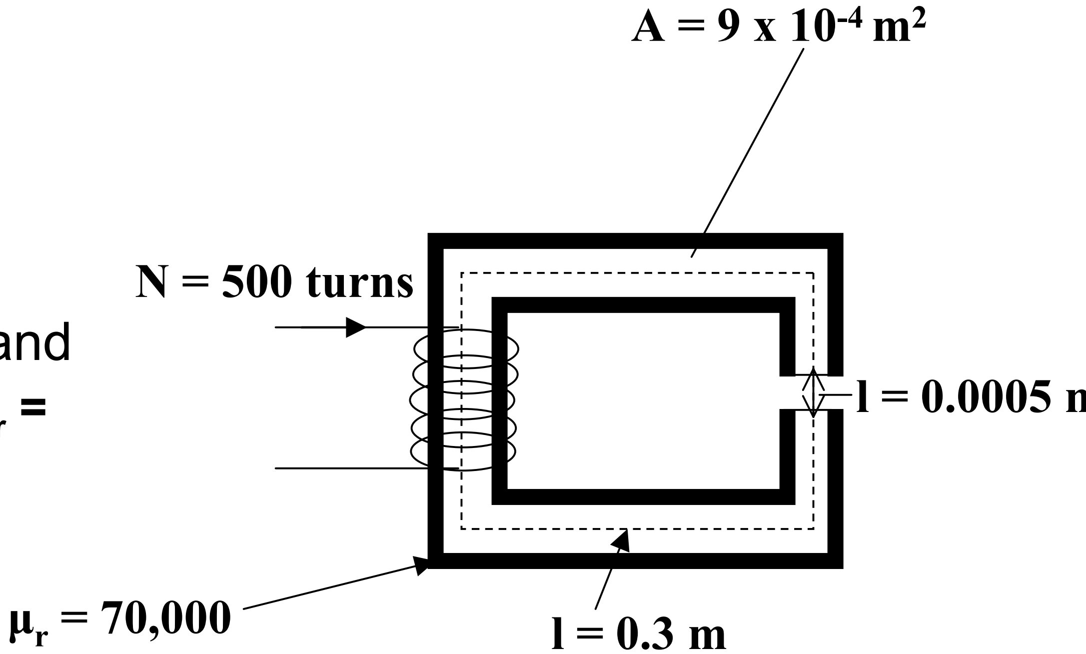
$$\mathbf{F} = NI = Hl$$

$$I = \frac{Hl}{N} = \frac{110 \times 0.16}{400} = 44\ mA$$

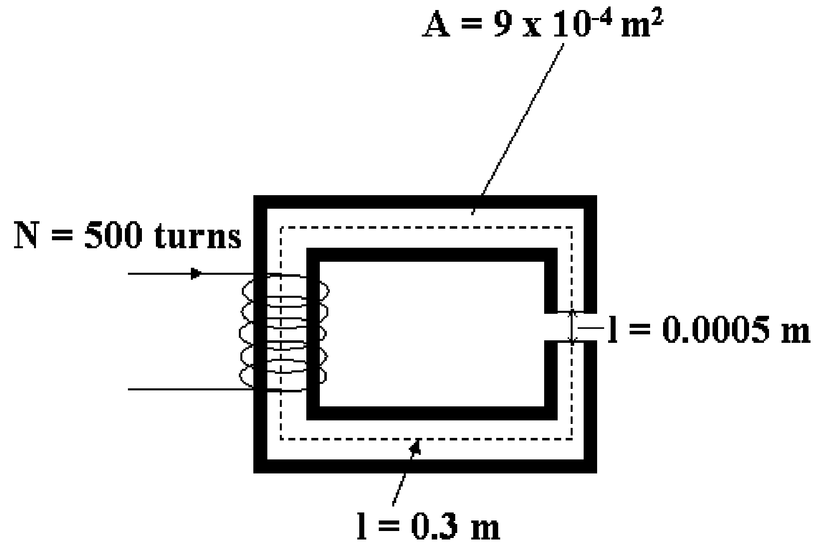


Example 2

- Find the flux if the flux density is 1.0 T
- The current in the coil
- The magnetic field strength in the air gap and in the magnetic core **(μ_r = 70,000)**



Example 2



$$A_c = A_g = 9 \times 10^{-4} m^2$$

$$l_g = 0.0005m$$

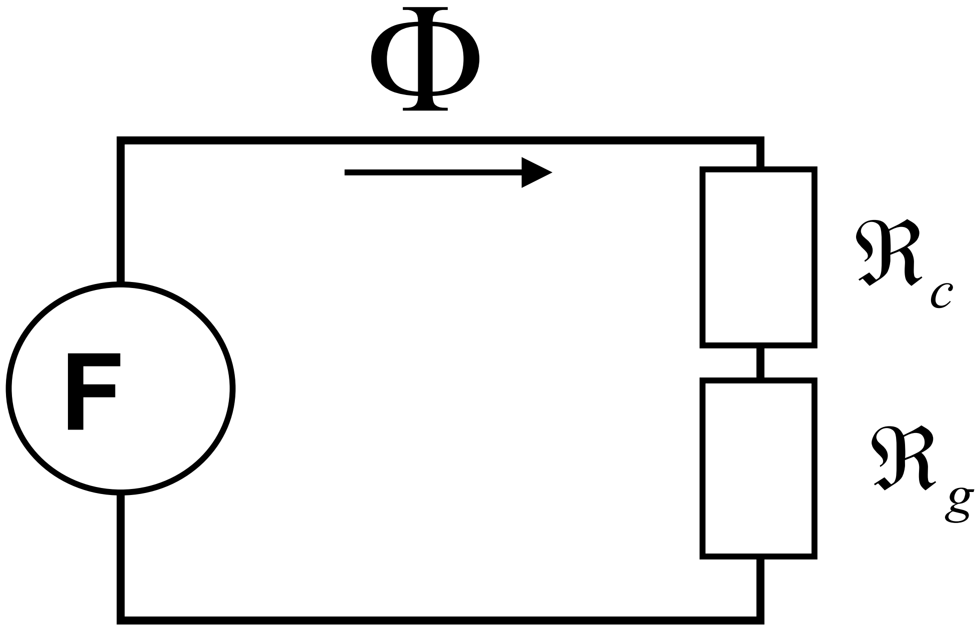
$$l_c = 0.3m$$

$$\Phi = \mathbf{B}A = 1.0 \times 9 \times 10^{-4} = 9 \times 10^{-4} Wb$$

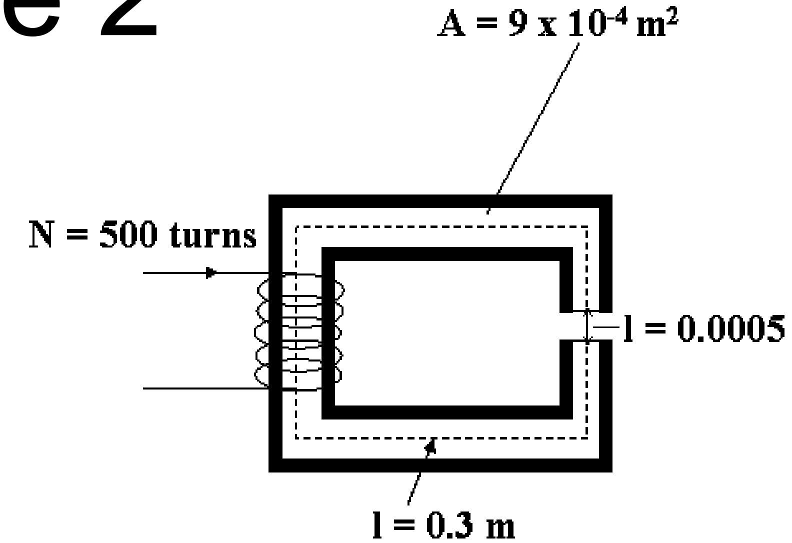
$$\mathbf{F} = \Phi \Re_c + \Phi \Re_g = \mathbf{F_c} + \mathbf{F_g}$$

To find current need to find MMF – use ohm's law equivalent!

Circuit Analogy



Example 2



Air Gap:

$$\Re_g = \frac{l_c}{\mu_o A_g} = \frac{5\times10^{-4}}{(4\pi\times10^{-7})(9\times10^{-4})}$$

$$= 4.42\times10^5\ At/Wb$$

$$F_g = \Phi\Re_g = 9\times10^{-4}\times4.42\times10^5 = 397.9\,At$$

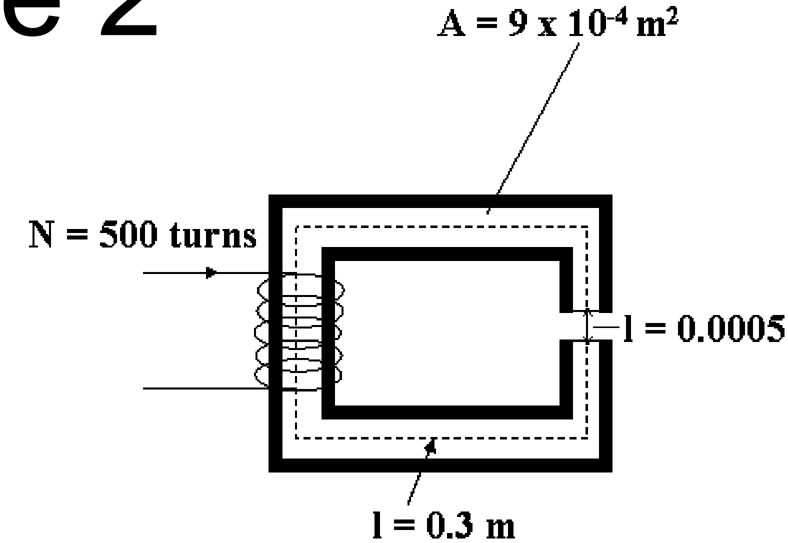
Core:

$$\Re_c = \frac{l_c}{\mu_r\mu_o A_c} = \frac{0.3}{(7\times10^4)(4\pi\times10^{-7})(9\times10^{-4})}$$

$$= 3789.4\ At/Wb$$

$$F_c = \Phi\Re_c = 9\times10^{-4}\times3789.4 = 3.41\,At$$

Example 2



F = F $_c$ + F$_g$

$$3.41 + 397.9 = 401.31\ At$$

$$I = \frac{F}{N} = \frac{401.31}{500} = 0.8A$$

Example 2

$$H_c = \frac{\mathbf{B}}{\mu_r \mu_o} = \frac{1}{(7\times 10^4)(4\pi\times 10^{-7})} = 11.37\,At/m$$

$$H_g = \frac{\mathbf{B}}{\mu_o} = \frac{1}{(4\pi\times 10^{-7})} = 7.96\times 10^5\,At/m$$