Electromagnetism

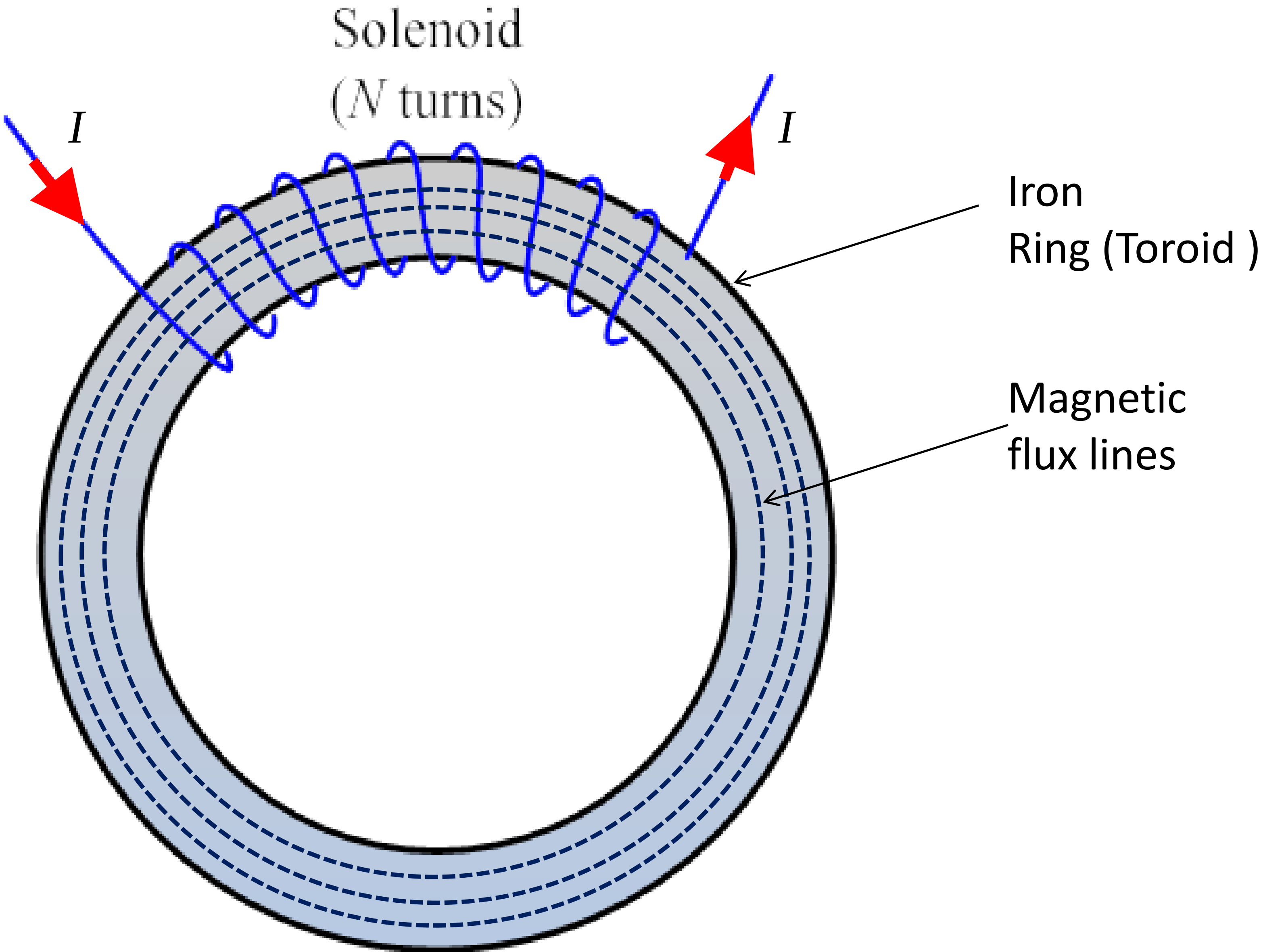
Day 19

ILOs – Day 19

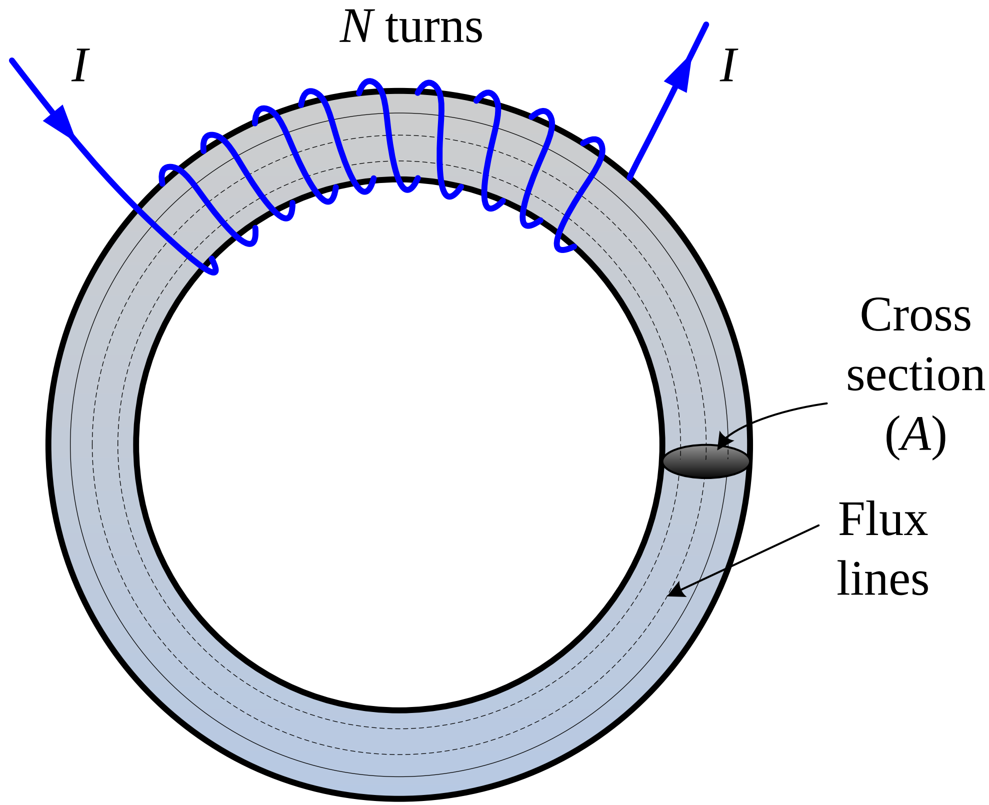
- Understand the basics of magnetic circuits
- Compare between magnetic and electric circuits
- Obtain mathematical relations for composite magnetic circuits
- Understand magnetic leakage and fringing

Magnetic Circuits

A magnetic circuit is defined as the path followed by magnetic flux



Magnetic Circuits



l = Total length of magnetic path along the toroid ring (i.e. average perimeter of the ring)

A = Area of cross section of the ring

N = number of turns in the solenoid

I = Current in the solenoid

Magnetic Circuits

Magnetic field intensity developed by the solenoid is:

$$H = \frac{NI}{l} \quad \text{AT/m}$$

Flux density within the core of the iron toroid is :

$$B = \mu_0 \mu_r H \quad \text{Wb/m}^2$$

The amount of flux flowing through the toroid :

$$\phi = BA$$

$$\phi = \mu_0 \mu_r HA$$

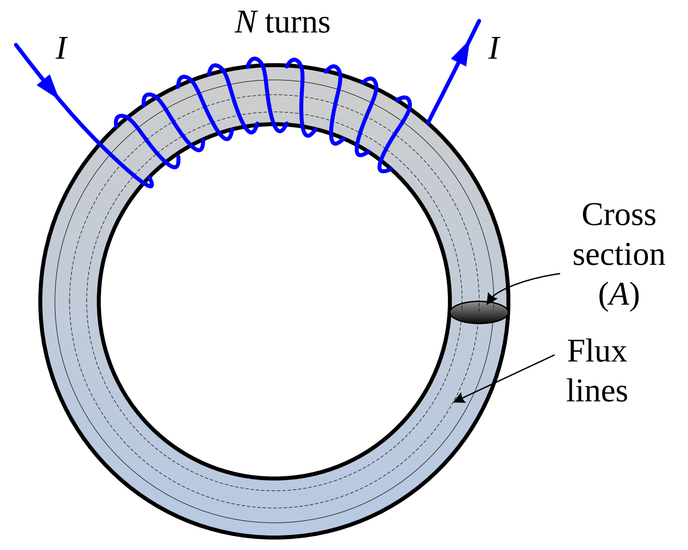
$$\phi = \mu_0 \mu_r \frac{NI}{l} A$$

$$\boxed{\phi = \frac{NI}{\dfrac{l}{\mu_0 \mu_r A}}}$$

Magnetic Circuits

$$\phi = \frac{NI}{\frac{l}{\mu_0 \mu_r A}}$$

Magneto Motive Force (MMF)



- MMF is the source that produces magnetism in a magnetic circuit
- MMF is analogous to EMF in an electric circuit
- MMF can be defined as the magnetic potential difference that forces magnetic flux to flow through a magnetic circuit
- MMF is expressed in the unit of Ampere-turns or in short AT

Magnetic Circuits

$$\phi = \frac{NI}{\dfrac{l}{\mu_0 \mu_r A}}$$

Magnetic reluctance

$$S = \frac{l}{\mu_0 \mu_r A}$$

$$\phi = \frac{NI}{S}$$

- ***Reluctance*** of the magnetic flux path is a measure of how much opposition the flux faces while flowing through the magnetic circuit
- It is analogous to resistance in electric circuits
- Property of a magnetic material that opposes the creation of flux in it
- Reluctance is inversely proportional to relative permeability (μ_r)
- It is obvious that a good magnetic material (high value of μ_r) will offer less opposition (low reluctance) to the flux flowing through it

$$\phi = \frac{MMF}{\text{Reluctance}}$$

Comparison between magnetic and electric circuits

Similarities

	Magnetic circuit	Electric circuit
Driving force	MMF (AT) = NI	EMF (Volts)
Effect	Flux, $\phi = \dfrac{MMF}{\text{Reluctance}}$	Current, $I = \dfrac{EMF}{\text{Resistance}}$
Density	Flux density, $B = \dfrac{\phi}{A}\ \text{Wb/m}^2$	Current density, $J = \dfrac{I}{A}\ \text{A/m}^2$
Opposition	Reluctance, $S = \dfrac{1}{\mu_0 \mu_r}\dfrac{l}{A}$	Resistance, $R = \rho \dfrac{l}{A}$
	Reluctivity, $\dfrac{1}{\mu_0 \mu_r}$	Resistivity, ρ
Allow	Permeability, $\mu_0 \mu_r$	Conductivity, $\sigma = \dfrac{1}{\rho}$

Comparison between magnetic and electric circuits

Differences

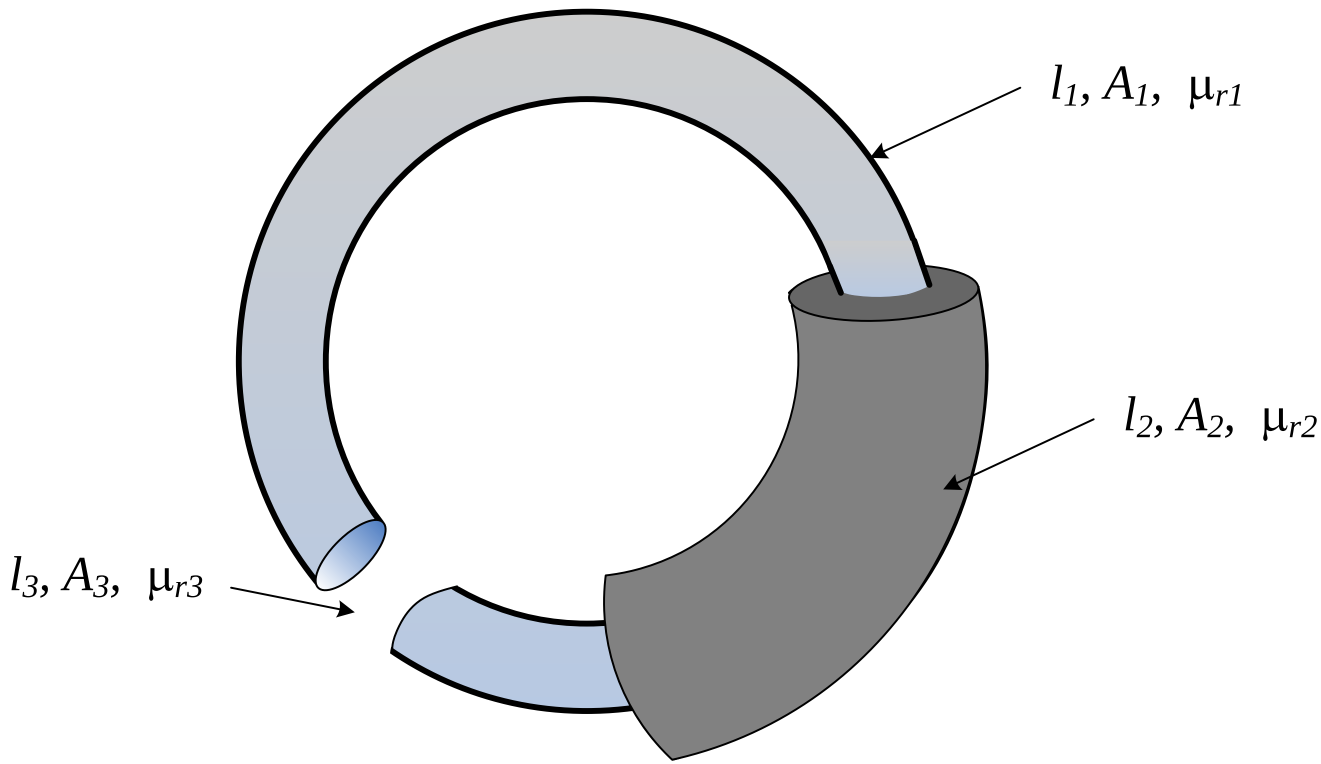
Magnetic circuit	Electric circuit
Magnetic flux can pass through almost anything	Electric current cannot pass through insulators
Magnetic flux can pass through air also	Electric current cannot pass through air (unless sparking)
Permeability of a material depends on flux and flux density	Resistivity does not depend on current (with constant temperature)
Some magnetic materials can retain magnetic property even after the source is removed	Current is immediately off in a conductor when the source is removed

Composite Magnetic Circuits

- Like electrical circuits can be made of series or parallel connection of different resistances, so are magnetic circuits.
- Magnetic circuits are often composed of more than one type of materials having different values of relative permeabilities.
- Thus, each part of the magnetic circuit will have different reluctance values

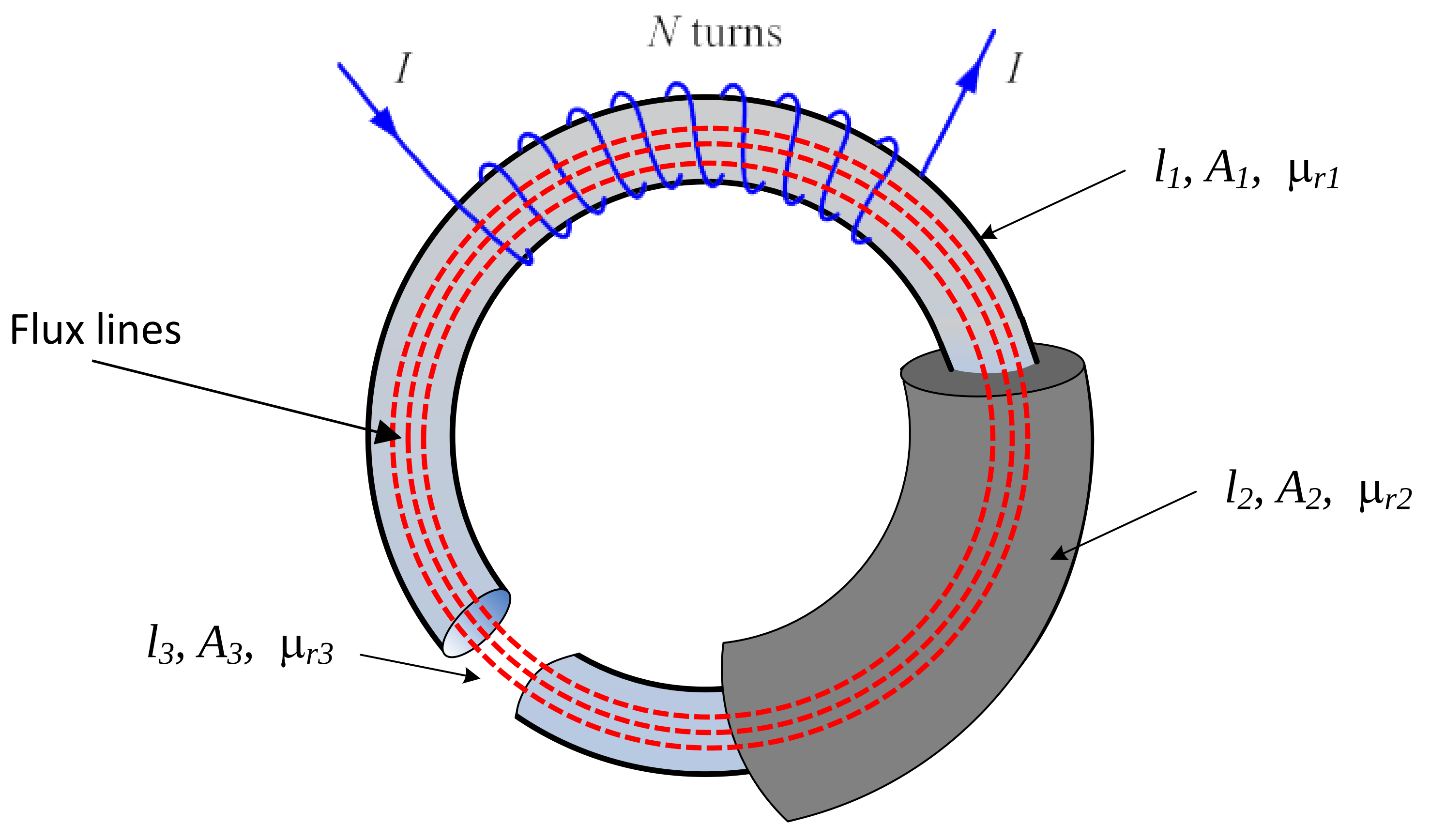
Series Magnetic Circuit

- The composite magnetic circuit shown below consists of three different magnetic materials of different permeabilitis, different lengths and may be different cross sections also
- Each part will have their own reluctance values

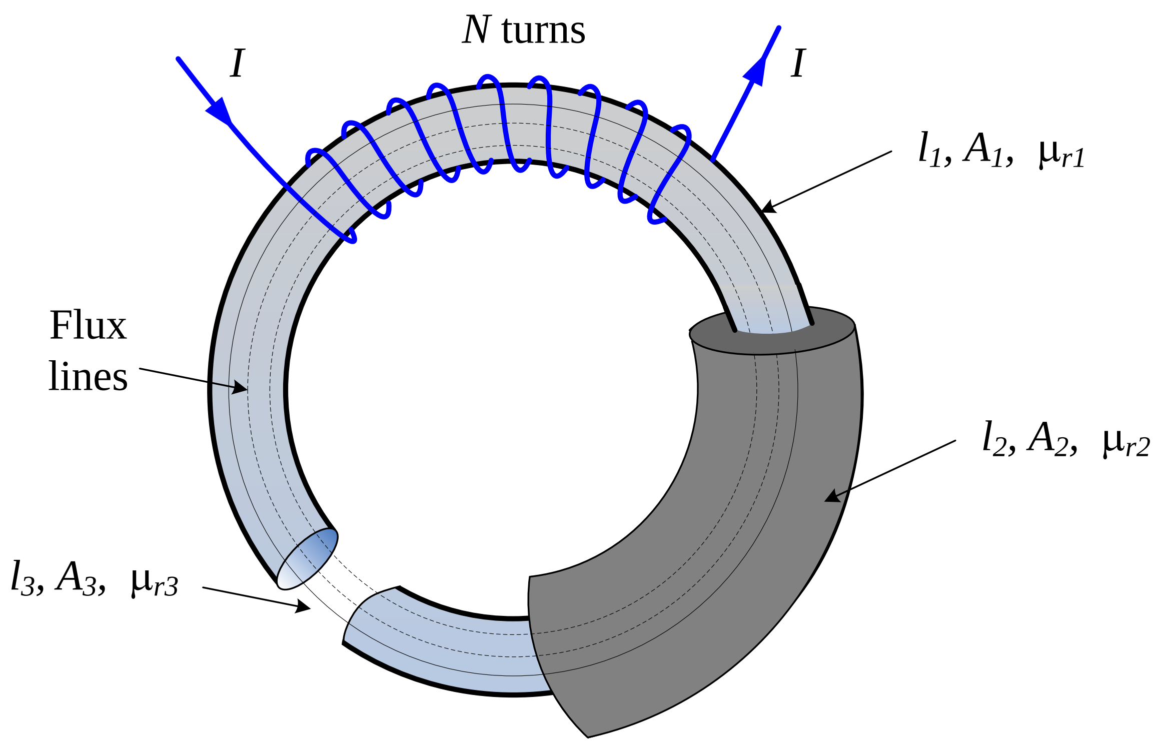


Series Magnetic Circuit

- The source of MMF (coil or solenoid) will drive flux through the composite circuit whose value will be decided by the overall reluctance.
- Same flux flows through all the three different parts (series circuit)



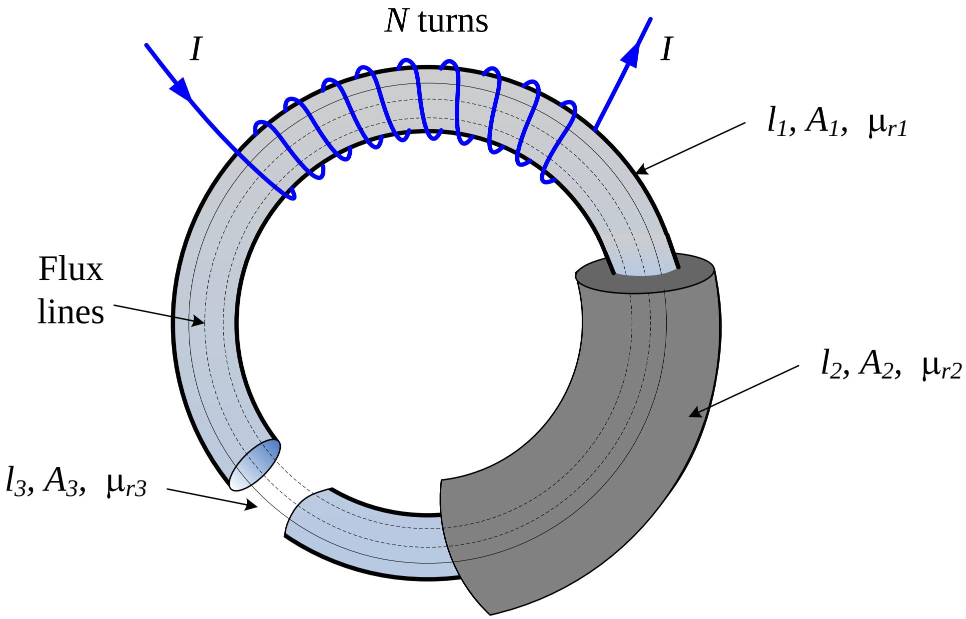
Series Magnetic Circuit



Total reluctance
$$S = \sum_i \frac{l_i}{\mu_0 \mu_{ri} A_i} = \frac{l_1}{\mu_0 \mu_{r1} A_1} + \frac{l_2}{\mu_0 \mu_{r2} A_2} + \frac{l_3}{\mu_0 \mu_{r3} A_3}$$

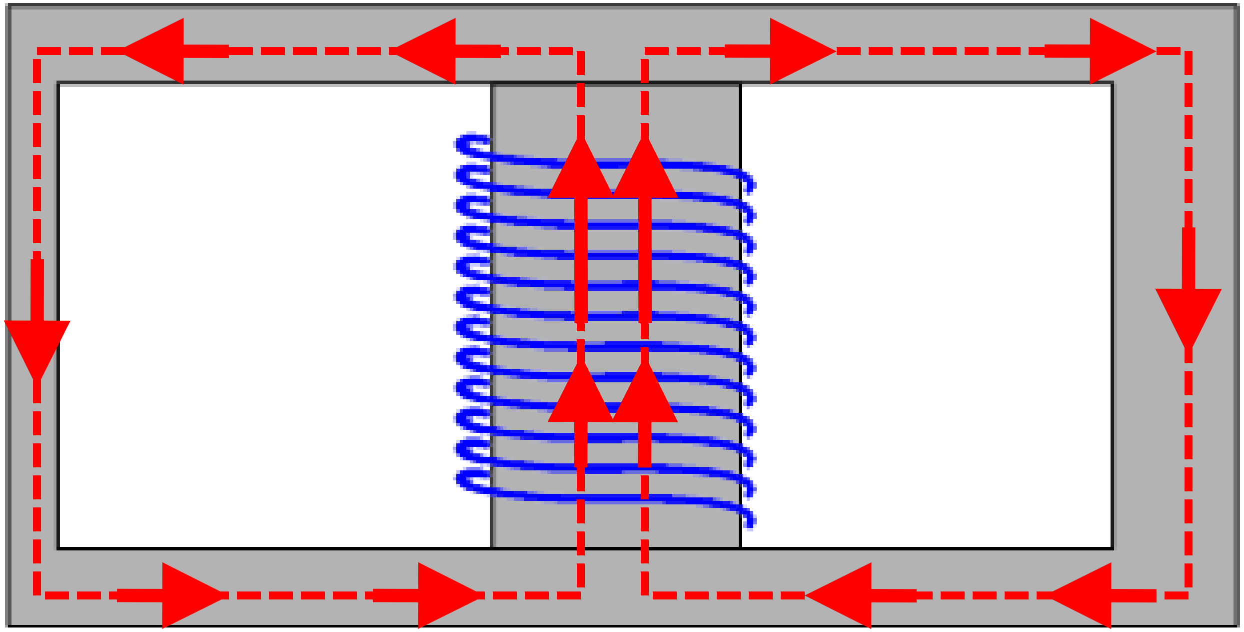
Resultant flux through the circuit
$$\phi = \frac{MMF}{\text{Reluctance}} = \frac{NI}{S} = \frac{NI}{\sum_i \frac{l_i}{\mu_0 \mu_{ri} A_i}}$$

Series Magnetic Circuit



- In a series electric circuit the same current flows through all parts of the circuit
- In a series magnetic circuit also, same flux flows through all parts of the circuit.
- Moreover, the total MMF required to drive flux through the entire circuit is summation of the MMFs required for individual parts of the series circuit.
- *This is like in electric circuit (KVL)*

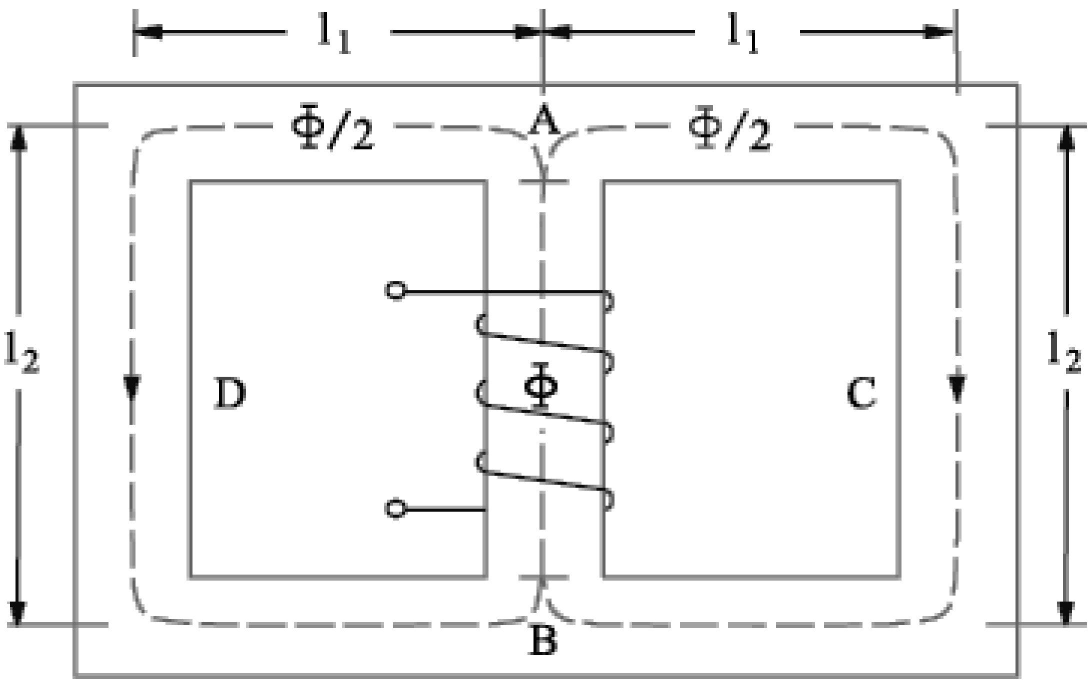
Parallel Magnetic Circuit

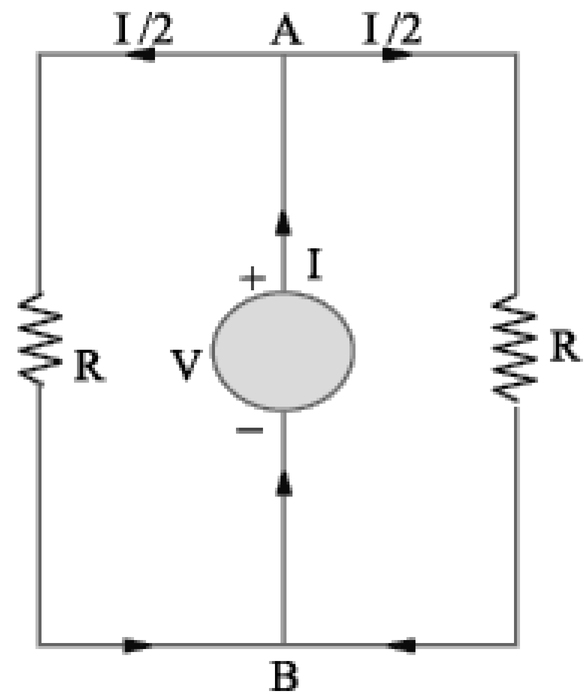


- In a parallel magnetic circuit, the flux gets divided among the branches
- ***Like current gets divided in parallel electric circuit***
- The MMF required is same for all the branches in parallel
- ***Like voltage is equal across each of the parallel branches in an electric circuit***

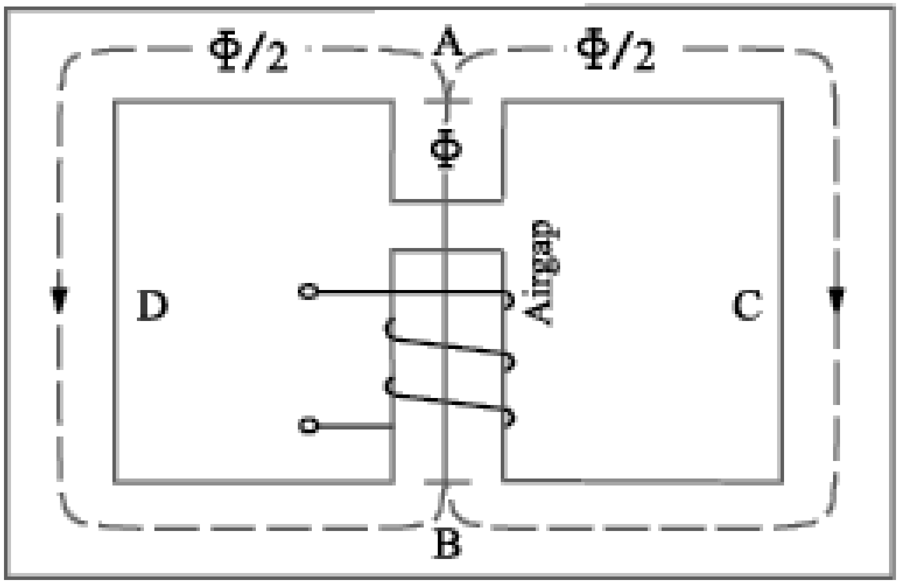
Parallel Magnetic Circuit

- Equivalent electrical and magnetic parallel circuits



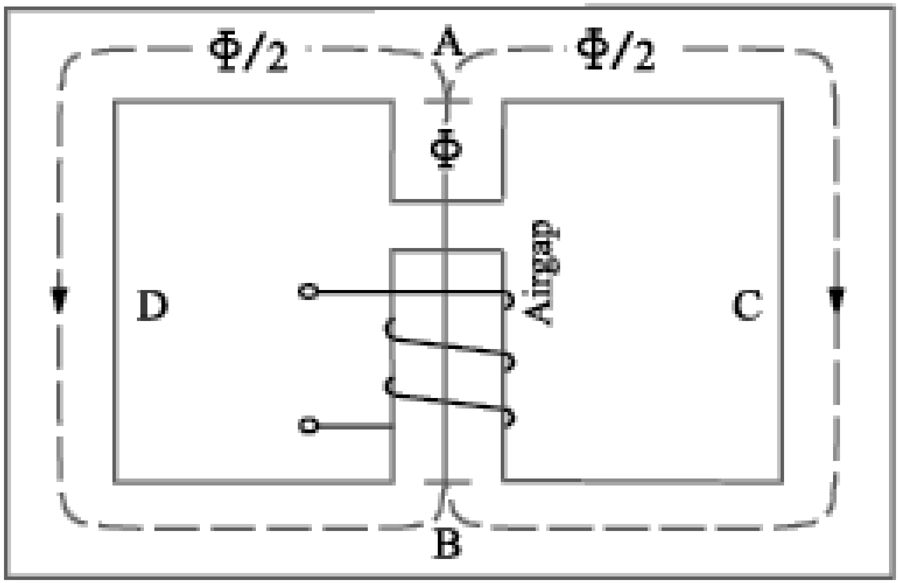


Series-Parallel Magnetic Circuit



- The figure shows two parallel magnetic circuits *ACB and ACD connected* across the common magnetic path *AB which contains an air-gap* of length l_g
- *As usual, the flux Φ in* the common core is divided equally at point *A between the two parallel* paths which have equal reluctance

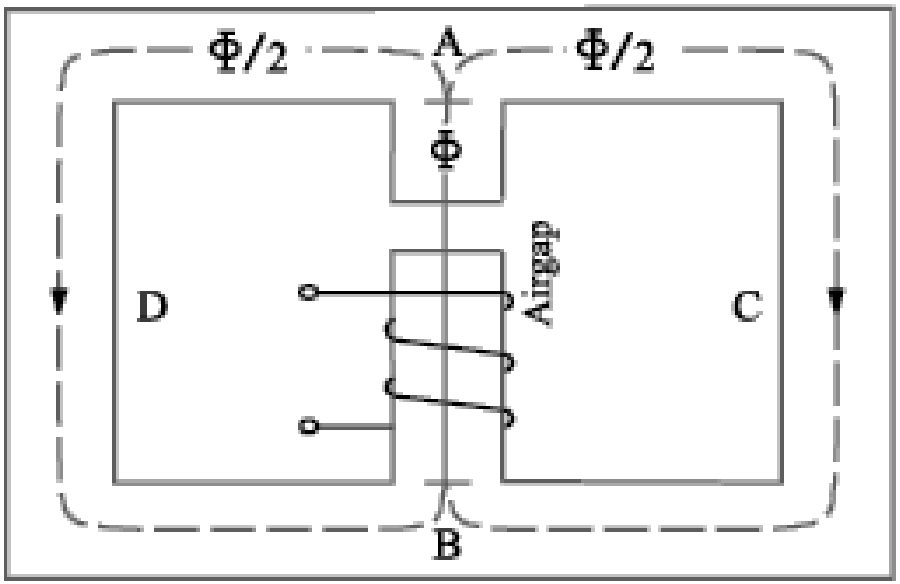
Series-Parallel Magnetic Circuit

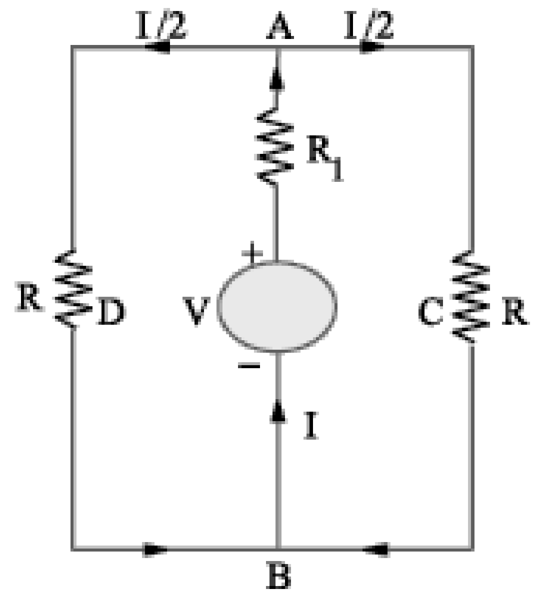


- The reluctance of the path *AB consists* of:
  - *air gap reluctance* and
  - the reluctance of the central core (which most of time is comparatively negligible)
- Hence, the *m.m.f. required for this circuit would be the sum of*
  - *that required for the air-gap* and
  - *that required for the two branches in parallel*

Series-Parallel Magnetic Circuit

- Equivalent electrical and magnetic circuits



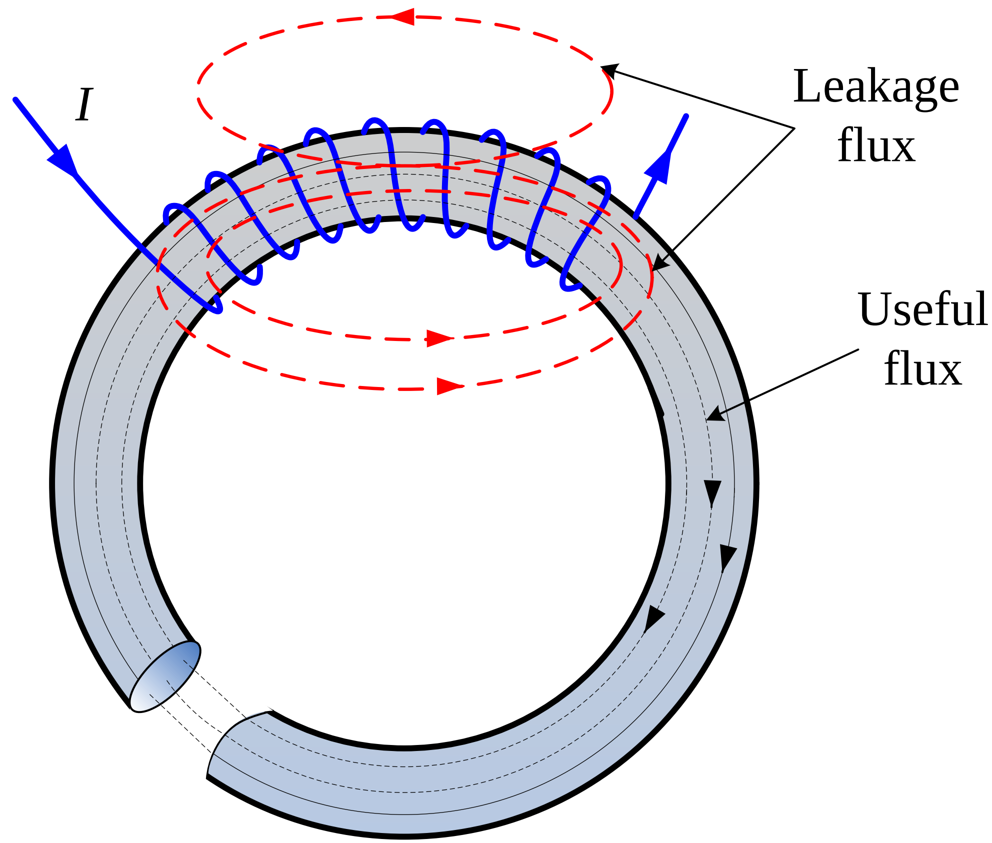


The total resistance offered to the voltage source in the equivalent electric circuit is = $R_1 + R//R = R_1 + R/2$

Similarly, the total reluctance offered to the MMF source in the equivalent magnetic circuit is = $S_1 + S//S = S_1 + S/2$

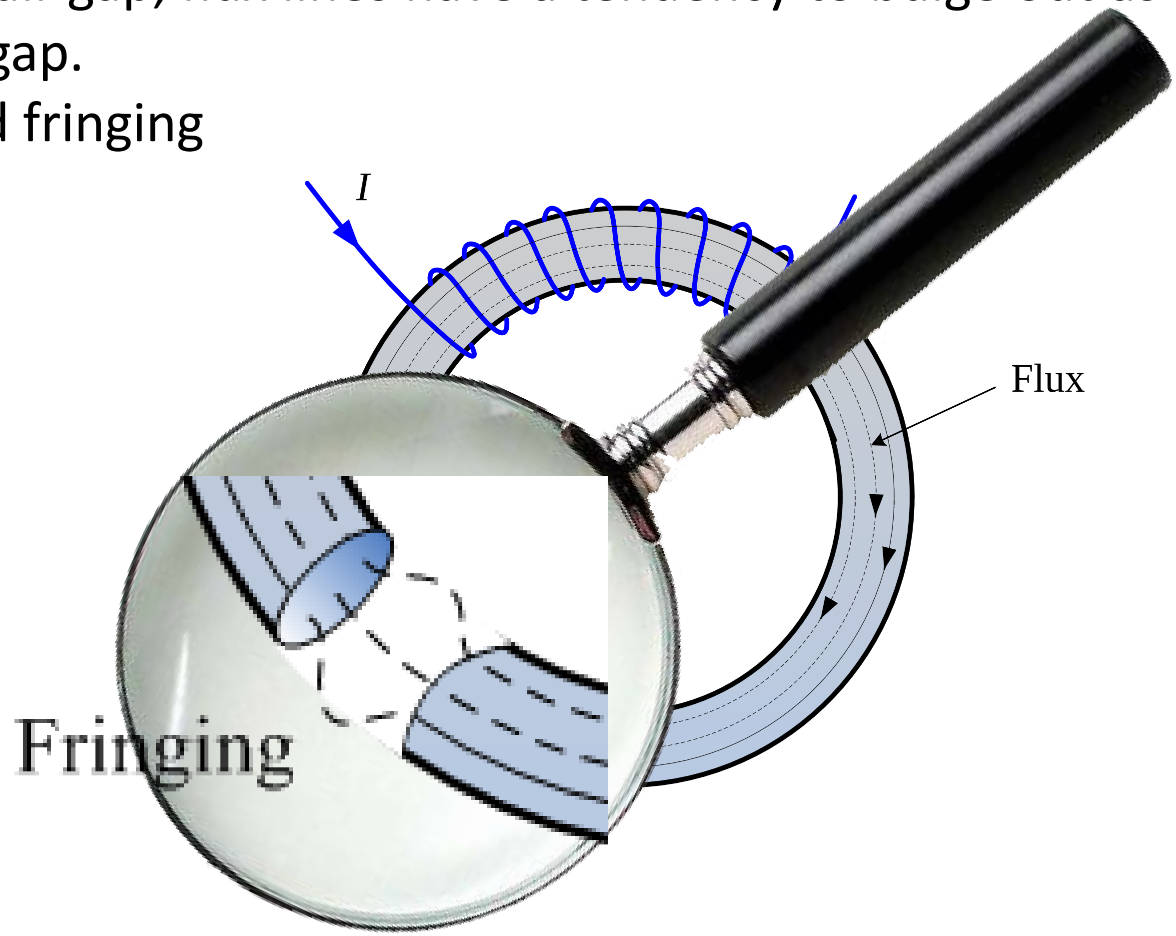
Flux leakage

- Leakage fluxes are those which do not flow through the entire length of the magnetic circuit, but complete their path through intermediate portions of the circuit.



Flux Fringing

- While crossing an air gap, flux lines have a tendency to bulge out as they cross the air gap.
- This effect is called fringing



- Fringing effect is more severe when length of the air gap is more.