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Subject: BASIC ELECTRICAL & ELECTRONICS ENGINEERING

Subject Code: BT-104

Unit: 3

Topic: MAGNETIC CIRCUIT

MAGNETIC CIRCUIT

- The closed path followed by magnetic lines of forces is called the **magnetic circuit**.
- In the **magnetic circuit**, magnetic flux or magnetic lines of force starts from a point and ends at the same point after completing its path.
- Flux is generated by magnets, it can be a permanent magnet or electromagnets.
- A **magnetic circuit** is made up of magnetic materials having high permeability such as iron, soft steel, etc.
- **Magnetic circuits** are used in various devices like electric motor, transformers, relays, generators galvanometer, etc.

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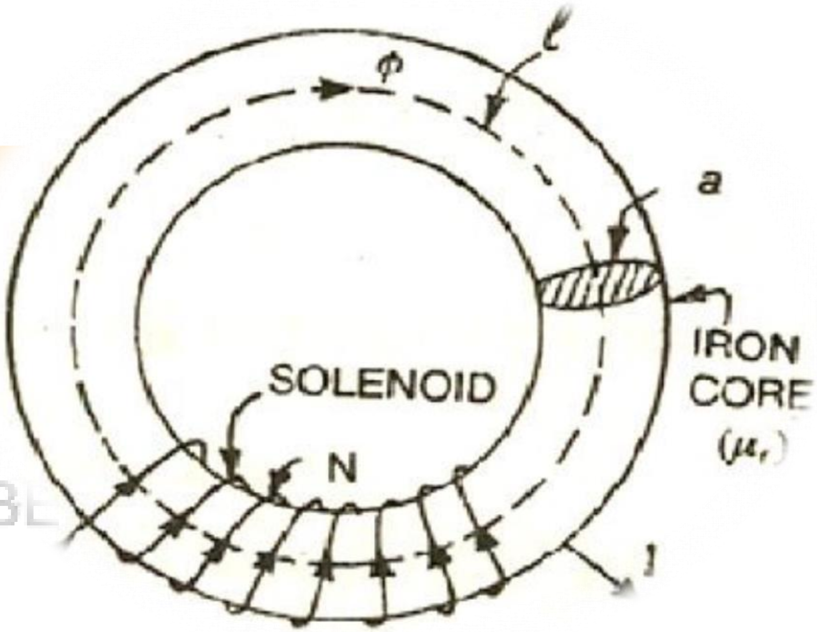
Consider a solenoid having N turns wound on an iron core.

The magnetic flux of ø Weber sets up in the core when the current of I ampere is passed through a solenoid



Let, l = mean length of the magnetic circuit

A = cross-sectional area of the core

μ_r = relative permeability of the core

Now the flux density in the core material

$$B = \frac{\varphi}{a} \quad (Weber/m^2)$$

Magnetising force in the core

$$H = B/\mu_0\mu_r$$

$$H = {}^{\varphi}/_{a}\,\mu_0\mu_r \text{ AT/m (Ampere turns/meter)}$$

According to work law, the work done in moving a unit pole once round the magnetic circuit is equal to the ampere-turns enclosed by the magnetic circuit.

$$Hl = NI$$

$$H = \frac{\varphi}{a\mu_0\mu_r} x\, l$$

$$H = NI$$

$$\varphi = \frac{NI}{l/a\mu_0\mu_r}$$

The above equation explains the following points:

1. Directly proportional to the number of turns (N) and current (I).
   It shows that the flux increase if the number of turns or current increases and decreases when either of the two quantity decreases. NI is the magneto motive force (MMF).
2. Inversely proportional to $l/a\mu_0\mu_r$, where ($l/a\mu_0\mu_r$) is known as reluctance. The lower the reluctance, the higher will be the flux and vice- verse.

Magnetic Flux

- The number of magnetic lines of forces set up in a magnetic circuit is called **Magnetic Flux**.
- It is analogous to electric current, I in an electric circuit.
- Its SI unit is Weber (Wb.) and its CGS unit is Maxwell.
- It is denoted by ϕ_m.
- The magnetic flux measures through flux meter.
- The flux meter has to measure coil which measures the variation of voltage to measure the flux.

Properties of magnetic flux

1. They always form a closed loop.
2. They always start from the North Pole and ends in the South Pole.
3. They never intersect each other.
4. Magnetic lines of forces that are parallel to each other and are in the same direction repel each other.

Magnetic Flux Density

- Flux density is the measure of the number of magnetic lines of force per unit of cross-sectional area.
- Flux per unit of cross-sectional area is called flux density.
- It is denoted by ϕ_m.

- If one line of magnetic field passes normally through m^2 area, the magnetic flux density, B, will be one Tesla.

The relationship between total flux and flux density is given by the following equation:

$$B = \frac{\varphi}{a} \quad (Weber/m^2)$$

Where
B=flux density in Tesla
ϕ=total magnetic flux in weber
a= Cross-sectional area in m^2

Magneto motive force (m.m.f.)

It drives or tends to drive flux through a magnetic circuit and corresponds to electromotive force (e.m.f.) in an electric circuit.

M.M.F. is equal to the work done in joules in carrying a unit magnetic pole once through the entire magnetic circuit.

It is measured in ampere-turns.

In fact, as p.d. between any two points is measured by the work done in carrying a unit charge from one points to another, similarly, m.m.f. between two points is measured by the work done in joules in carrying a unit magnetic pole from one point to another.

Ampere-turns (AT)

It is the unit of magneto motive force (m.m.f.) and is given by the product of number of turns of a magnetic circuit and the current in amperes in those turns.

Reluctance

It is the name given to that property of a material which opposes the creation of magnetic flux in it.

It, in fact, measures the opposition offered to the passage of magnetic flux through a material and is analogous to resistance in an electric circuit even in form.

Its units is AT/Wb.

In other words, the reluctance of a magnetic circuit is the number of amp-turns required per weber of magnetic flux in the circuit. Since 1 AT/Wb = 1/henry, the unit of reluctance is "reciprocal henry."

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Composite Series Magnetic Circuit

In Fig. shown a composite series magnetic circuit consisting of three different magnetic materials of different permeabilities and lengths and one air gap ($\mu_r = 1$).

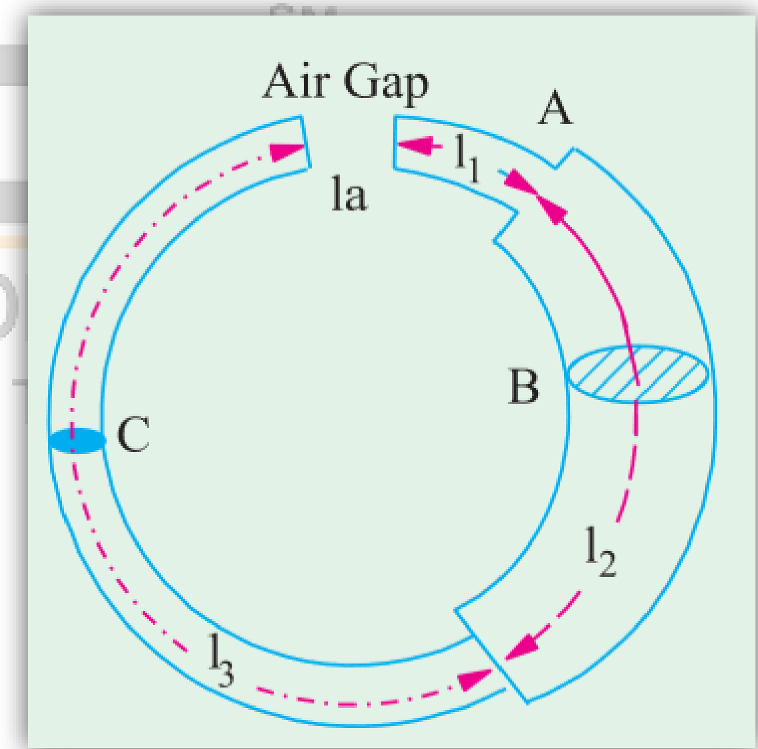
Each path will have its own reluctance.

The total reluctance is the sum of individual reluctances as they are joined in series.

$$\text{total reluctance} = \Sigma \frac{l}{\mu_0 \mu_r A}$$

$$= \frac{l_1}{\mu_0 \mu_{r_1} A_1} + \frac{l_2}{\mu_0 \mu_{r_2} A_2} + \frac{l_3}{\mu_0 \mu_{r_3} A_3} + \frac{l_a}{\mu_0 A_g}$$

$$\text{flux } \Phi = \frac{\text{m.m.f.}}{\dfrac{l}{\mu_0 \mu_r A}}$$



How to Find Ampere-turns?

$H = NI / \ell$ AT/m or $NI = H \times \ell$

$\therefore$ Ampere-turns $AT = H \times \ell$

Hence, following procedure should be adopted for calculating the total ampere turns of a composite magnetic path.

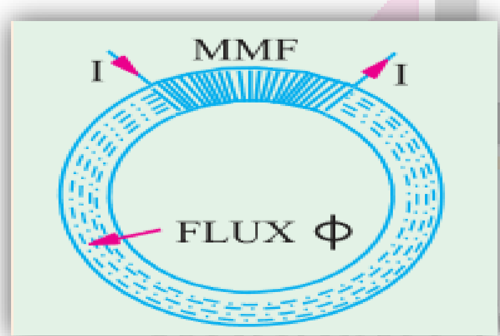
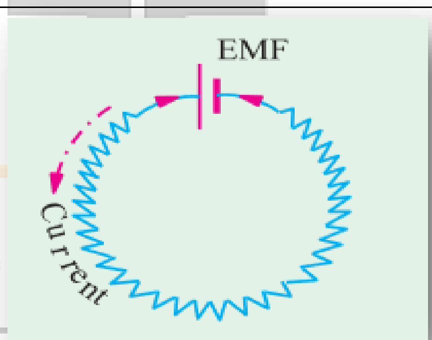
(i) Find H for each portion of the composite circuit. For air, $H = B/\mu_0$, otherwise $H = B/\mu_0\mu_r$.

(ii) Find ampere-turns for each path separately by using the relation $AT = H \times \ell$.

(iii) Add up these ampere-turns to get the total ampere-turns for the entire circuit.

Comparison between Magnetic and Electric Circuits.

SIMILARITIES

Magnetic Circuit	Electric Circuit
	
Flux = m.m.f. /reluctance	Current = e.m.f. / resistance
M.M.F. (ampere-turns)	E.M.F. (volts)
Flux Φ (webers)	Current I (amperes)
Flux density B (Wb/m^2)	Current density (A/m^2)

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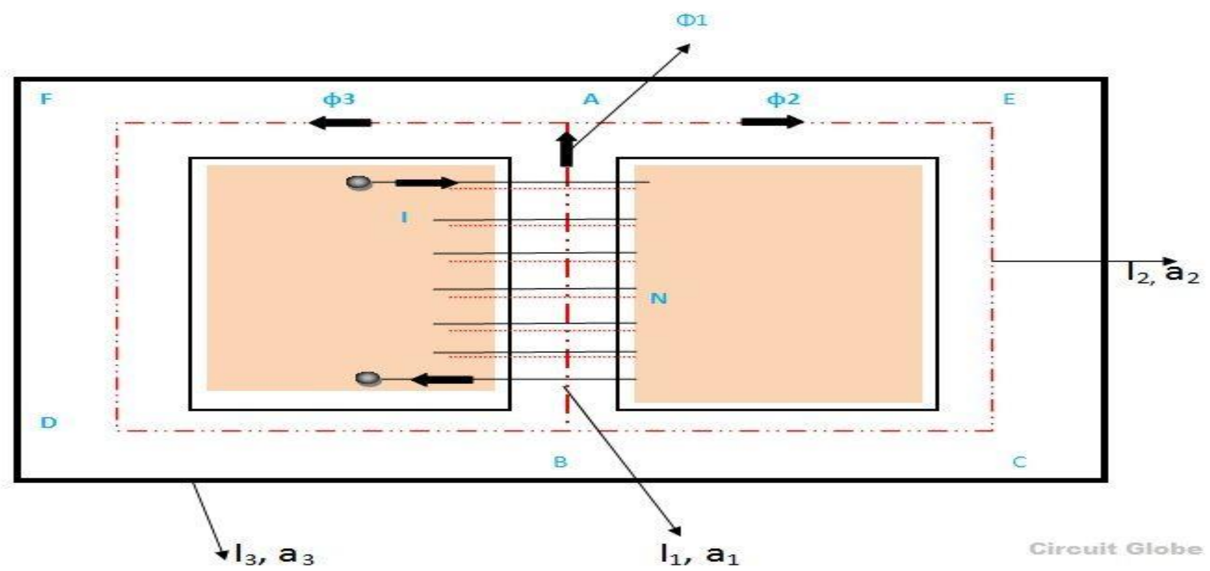
Reluctance S = $\frac{l}{\mu.A}$	Resistance R =ρ$\frac{l}{A}$
Permeance (= 1/reluctance)	Conductance (= 1/resistance)
Reluctivity	Resistivity
Permeability (= 1/reluctivity)	Conductivity (= 1/resistivity)
Total m.m.f. = $\Phi S_1 + \Phi S_2 + \Phi S_3 +.....$	Total e.m.f. = $IR_1 + IR_2 + IR_3 +.....$

DISIMILARITIES

In the magnetic circuit, magnetic flux flows through the path.	In an electric circuit, electric current flows through the path.
Magnetic flux flows from N-pole to S-pole	Electric current flows from positive to negative polarities
The magnetic circuit is always a closed circuit.	The electric circuit can be closed or open circuit.
Flow of current in an electric circuit involves continuous expenditure of energy.	In a magnetic circuit, energy is needed only creating the flux initially but not for maintaining it.

Parallel Magnetic Circuit

- A magnetic circuit having two or more than two paths for the magnetic flux is called a **parallel magnetic circuit**.
- Its behavior can be compared to the parallel electric circuit.
- The parallel magnetic circuit contains different dimensional areas and materials having various numbers of paths.



The above figure shows a parallel magnetic circuit.

In this circuit, a current-carrying coil is wound on the central limb AB.

This coil sets up the magnetic flux ϕ_1 in the central limb of the circuit.

The flux ϕ_1 which is in the upward direction is further divided into two paths namely ADCB and AFEB.

The path ADCB carries flux ϕ_2, and the path AFEB carries flux ϕ_3.

It is clearly seen from the above circuit that

$$\phi_1 = \phi_2 + \phi_3$$

The two magnetic paths ADCB and AFEB form the parallel magnetic circuit, thus, the ampere-turns (ATs) required for this parallel circuit are equal to the ampere-turns (ATs) required for any one of the paths.

As we know, reluctance is $S = \frac{l}{a_1 \mu_0 \mu_{r1}}$

If S_1 = reluctance of path BA will be $S_1 = \frac{l_1}{a_1 \mu_0 \mu_{r1}}$

S_2 =reluctance of path ADCB will be $S_2 = \frac{l_2}{a_2 \mu_0 \mu_{r2}}$

S_3 = reluctance of the path AFEB will be $S_3 = \frac{l_3}{a_3 \mu_0 \mu_{r3}}$

Therefore, the total MMF or the total Ampere turns required in the parallel magnetic circuit will be the sum of all the individual parallel paths.

Total mmf required

= mmf required for the path BA + mmf required for the path ADCB+ mmf required for the path AFEB

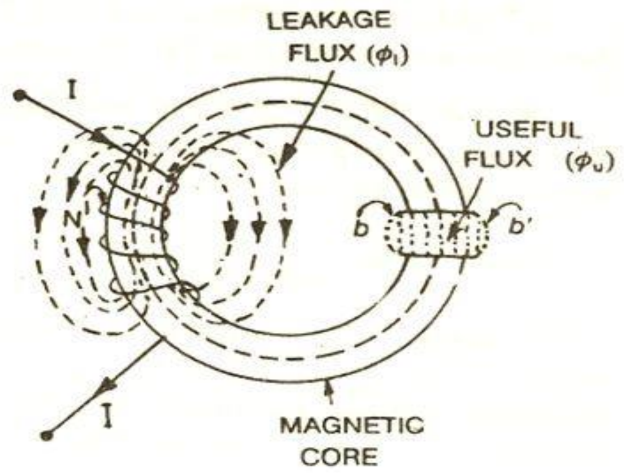
$$\text{Total mmf or Ampere turns} = \varphi_1 S_1 + \varphi_2 S_2 + \varphi_3 S_3$$

Where ϕ_1. Φ_2, ϕ_3 is the flux and S_1, S_2, S_3 are the reluctances of the parallel path BA, ADCB and AFEB respectively.

Leakage Flux and Fringing

Leakage flux is defined as the magnetic flux which does not follow the particularly intended path in a magnetic circuit. Taking an example of solenoid you can explain the **leakage flux** and the fringing both.

When a current is passed through a solenoid, magnetic flux is produced by it.



Most of the flux is set up in the core of the solenoid and passes through the particular path that is through the air gap and is utilised in the magnetic circuit.

This flux is known as **Useful flux** ϕ_u.

As practically it is not possible that all the flux in the circuit follows a particularly intended path and sets up in the magnetic core and thus some of the flux also sets up around the coil or surrounds the core of the coil, and is not utilized for any work in the magnetic circuit.

This type of flux which is not used for any work is called **Leakage Flux** and is denoted by ϕ_l.

Therefore, the total flux **Φ** produced by the solenoid in the magnetic circuit is the sum of the **leakage flux** and the useful flux and is given by the equation shown below:

$$\varphi = \varphi_u + \varphi_l$$

Leakage coefficient

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The ratio of the total flux produced to the useful flux set up in the air gap of the magnetic circuit is called a leakage coefficient or leakage factor. It is denoted by (λ).

$$\lambda = \frac{\varphi}{\varphi_u}$$

Fringing

The useful flux when sets up in the air gap, it tends to bulge outward at (b and b') as shown in above figure, because of this bulging, the effective area of the air gap increases and the flux density of the air gap decreases. This effect is known as **Fringing.**

Fringing is directly proportional to the length of the air gap that means if the length increases the fringing effect will also be more and vice versa.

Residual Magnetism

The value of the flux density retained by the magnetic material is called residual magnetism, and the power of retaining it is known as **Retentivity of the material**.

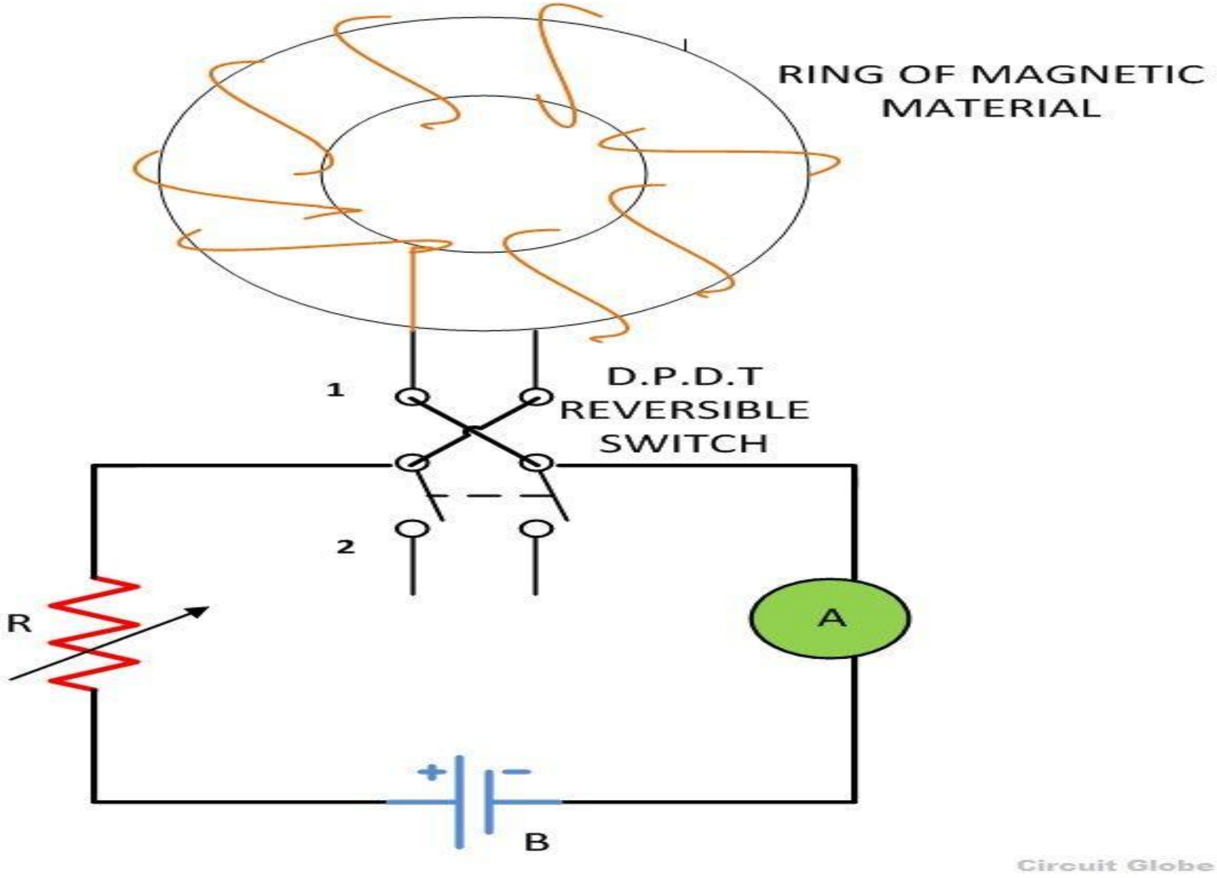
Magnetic Hysteresis

The phenomenon of flux density B lagging behind the magnetizing force H in a magnetic material is known as **Magnetic Hysteresis.**

In other words, when the magnetic material is magnetized first in one direction and then in the other direction, completing one cycle of magnetization, it is found that the flux density B lags behind the applied magnetization force H.

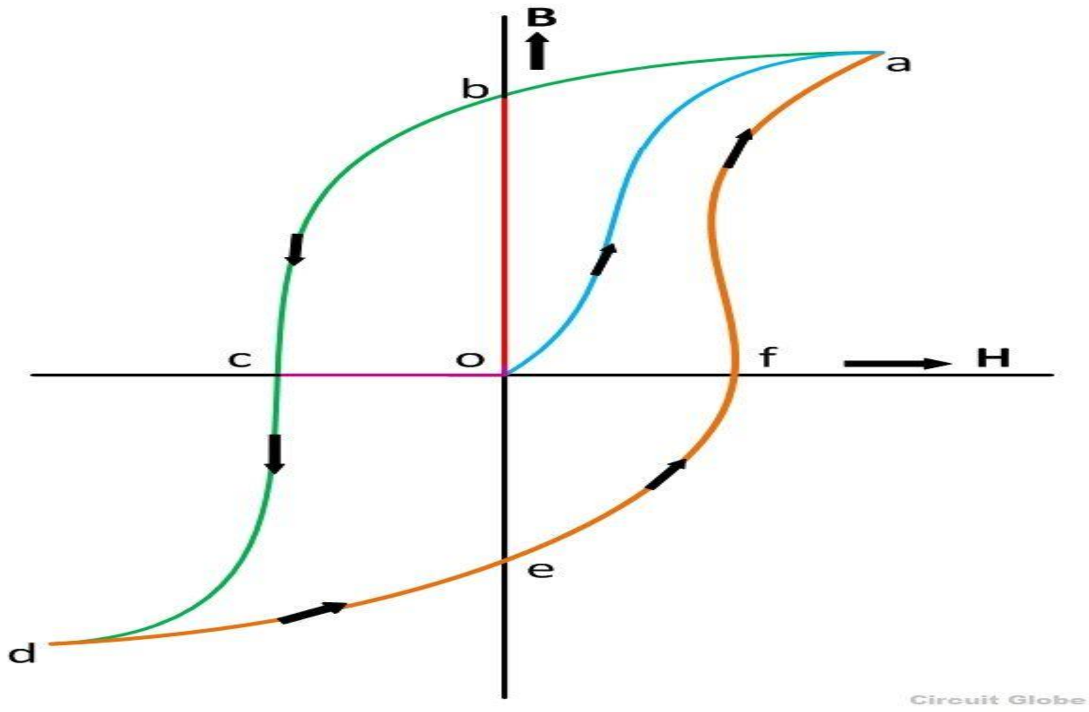
There are various types of magnetic materials such as paramagnetic, diamagnetic, ferromagnetic, ferromagnetic and antiferromagnetic materials. Ferromagnetic materials are mainly responsible for the generation of the hysteresis loop.

For understanding the phenomenon of the magnetic hysteresis, consider a ring of magnetic material wound uniformly with solenoid. The solenoid is connected to a DC source through a Double pole double throw (D.P.D.T) reversible switch as shown in the figure below:



Initially, the switch is in position 1. By decreasing the value of R the value of the current in the solenoid increases gradually resulting in a gradual increase in field intensity H, the flux density also increases till it reaches the saturation point a and the curve obtained is ‘**oa**‘. Saturation occurs when on increasing the current, dipole moment or the molecules of the magnet material align itself in one direction.

Now by decreasing the current in the solenoid to zero the magnetizing force is gradually reduced to zero. But the value of flux density will not be zero as it still has the value ‘**ob**‘ when H=0, so the curve obtained is ‘**ab**‘ as shown in the figure below. This value ‘**ob**‘ of flux density is because of the residual magnetism.



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ASSIGNMENTS

Q.1 Explain the following:

(i) Magnetic flux and magnetic flux density

(ii) Leakage flux and fringing

(iii) MMF, reluctance, permeability.

Q.2 Make comparison between the electric and magnetic circuit.

Q.3 Explain series and parallel magnetic circuit.

Q.4. What is B-H curve? Also explain hysteresis and eddy current loss.

Q.5 A flux density of is required in the 2 mm air gap of an electromagnet having an iron path 1 m long calculate the magnetizing force and current required if the electromagnet has 1273 turns assume relative permeability of iron to be 1500.

Q.6 The magnetic circuit shown in figure it built up of iron of square cross section 2 cm wide each air gap is 2 mm wide permeability for part a may be taken as 900 and as part B as 1250 . Each of the exciting coils is wound with 1200 turns and exciting coil is carrying current of 0.8 amp find:

(1) Reluctance of A (2) Reluctance of B (3) Reluctance of two air gaps

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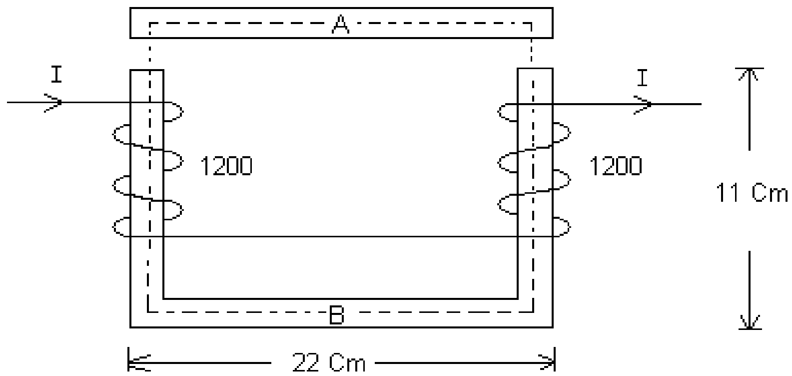
(4)Total reluctance (5) Total flux (6) Flux density

Neglect leakage and fringing.



Q.6 A cast steel ring of mean circumference 50cm having a cross section of 0.52 cm^2. It has saw cut of 1mm at one place. Giving the following data

B(wb./m^2)	1	1.25	1.46	1.60
μ_r	714	520	360	247

Calculate how many ampere turns are required to produce a flux of 0.052 mWb, if the leakage factor is 1.2.

Q.7 A steel ring of circular section of 1 cm in radius and having a mean circumference of 94.3 cm and air gap of 1mm long it is uniformly wound with an exciting coil consisting of 600 turns and excite4d with a current of 2.5 amp. Neglecting magnetic leakage. Calculate (i) MMF (ii) Magnetic flux (iii) Reluctance (iv) Flux density (v) Relative permeability of steel.

Assume that steel part takes about 40% of total ampere turns (AT)

Q.8 A rectangular shape core is made of mild steel plate 50mmX20mm cross section. The mean length of the magnetic path is 18 cm the exciting coil has 300 turns and current of 0.7 amp. Calculate:

(i) magnetizing force (ii) Flux density (iii) Reluctance (iv) Flux of magnetic circuit.

Assuming relative permeability of mild steel as 940.

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