AKTU

B. Tech I-Year

Gateway Classes

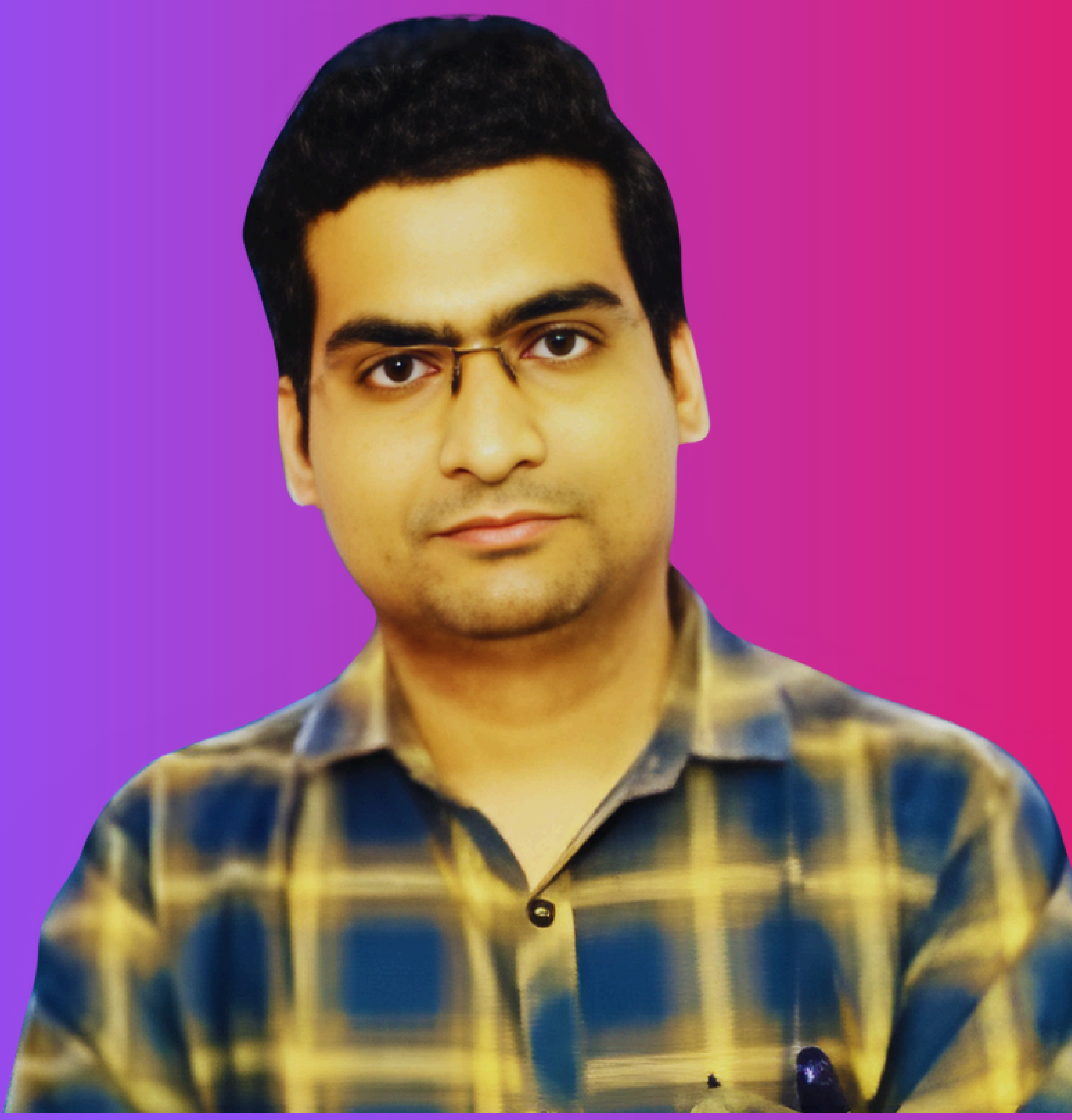
GATEWAY CLASSES

Semester -I & II

Common to All Branches

BEE101/201: FUNDAMENTALS OF ELECTRICAL ENGG.

UNIT-3 ONE SHOT : Transformers



Gateway Series for Engineering

- Topic Wise Entire Syllabus
- Long - Short Questions Covered
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AKTU

B. Tech I-Year

Gateway Classes

BEE101 / BEE201: FUNDAMENTALS OF ELECTRICAL ENGINEERING

Unit-3
Introduction to Transformers

Syallbus

Magnetic circuits, ideal and practical transformer, equivalent circuit, losses in transformers, regulation and efficiency.


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GATEWAY CLASSES
Electrical Engg
One Shot
UNIT - III

- **Unit-3:** (Transformers)

- Magnetic circuits,
- ideal and practical transformer,
- equivalent circuit, → Num.
- losses in transformers,
- regulation and efficiency. → Num

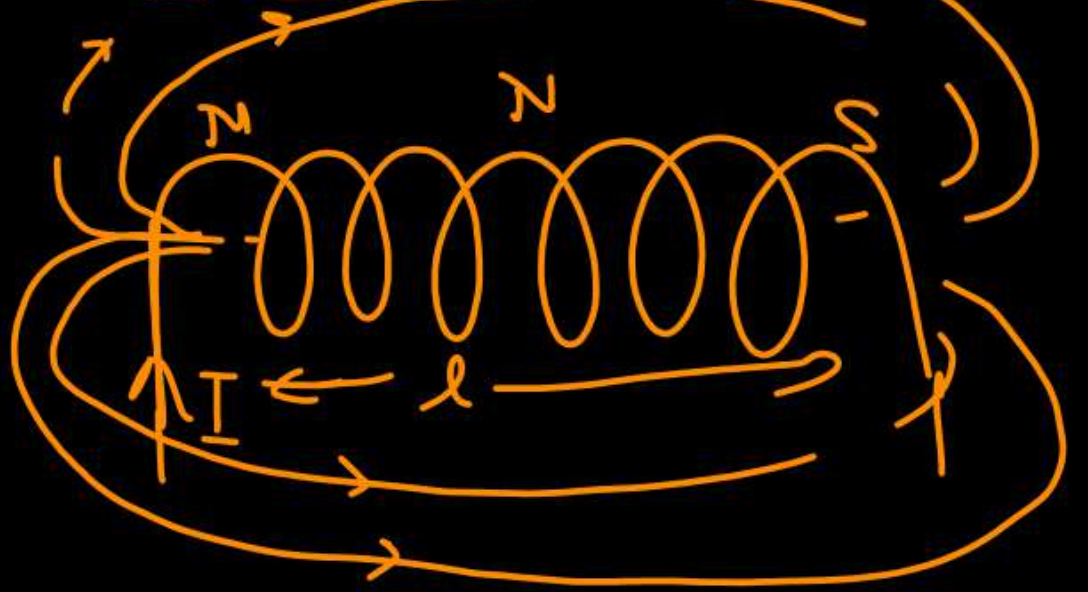
Basic Definitions

1. **Magnetic Field:-** Area around a magnet within which it influence its perceptible is known as magnetic field.

2. **Magnetic Flux :-** total number of magnetic field lines passing through a given surface. unit of flux is Weber (Wb). 1 wb = 10^8 line of force

3. **Magnetic Flux density :-** Flux per unit area is known as flux density $(B) = \frac{flux}{area}$

$\frac{flux}{area}$



4. **Magnetic field intensity:-** Magnetizing force or Magnetic field intensity or magnetic field strength is the MMF required to magnetize a unit length of the magnetic flux path. The unit of magnetic field intensity is AT/m and is denoted by H.

$$H = \frac{NI}{l}$$

AT/m

AT/m

$$\boxed{H = \frac{NI}{l}}$$

Basic Definitions

5. Magneto-motive force or MMF:- MMF is the cause for producing the magnetic flux. The MMF in a magnetic circuit depends on the number of turns(N) and the amount of current(I) flowing through it.

$$MMF = NI$$

unit is ampere turns. AT

6 Reluctance:- It is the opposition that the magnetic circuit offers for the flow of magnetic flux. We can also define the reluctance as the ratio of magneto-motive force to the magnetic flux. It is denoted by S and its unit is ampere-turns per weber.

$$Reluctance(S) = \frac{mmf}{Flux} = \frac{l}{A\mu_o\mu_r} = \frac{l}{\mu A} = \frac{\overset{mmf}{NI}}{\phi}$$

$$\boxed{S = \frac{1}{\mu}\frac{l}{a}}$$

$$Resistance = \frac{V}{I} =$$

$$R = \rho\frac{l}{a}$$

7. Permeance:- Permeance is the reciprocal of reluctance. The ease with which the flux can pass through the material is known as permeance. Weber/AT is the unit of permeance.

8. Permeability:- Permeability is the ability of a material to allow the magnetic flux when the object is placed inside the magnetic field.

$$\mu = \mu_o\mu_r$$

Where μ_o is absolute permeability ($4\pi \times 10^{-7}$) and $\mu_r = 1\ for\ air$ is relative permeability

Magnetic Circuit

Magnetic Circuit:- The closed path followed by the magnetic flux is magnetic circuit.

The laws of magnetic circuits are quite similar to the electric circuits.

A **magnetic circuit** is made up of magnetic materials having high permeability such as iron, soft steel, etc. 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

μr = relative permeability of the core

$B = \mu H = \mu_0\mu_r . H$

Now the Field Strength is given by

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

$$B = \mu_o\mu_r H = \frac{\mu_o\mu_r NI}{l}\ Wb/m^2 \text{ Wb}$$

$$\text{Total Flux}\emptyset = B \times A = \frac{\mu_o\mu_r NIA}{l} = \frac{NI}{\frac{l}{A\mu_o\mu_r}} \text{ Wb.}$$

$\phi = B \times A = \frac{\mu_0\mu_r . H A}{A} = \frac{\mu_0\mu_r NIA}{l}$

$NI \rightarrow mmf$, $\frac{l}{A\mu_0\mu_r} \rightarrow S$

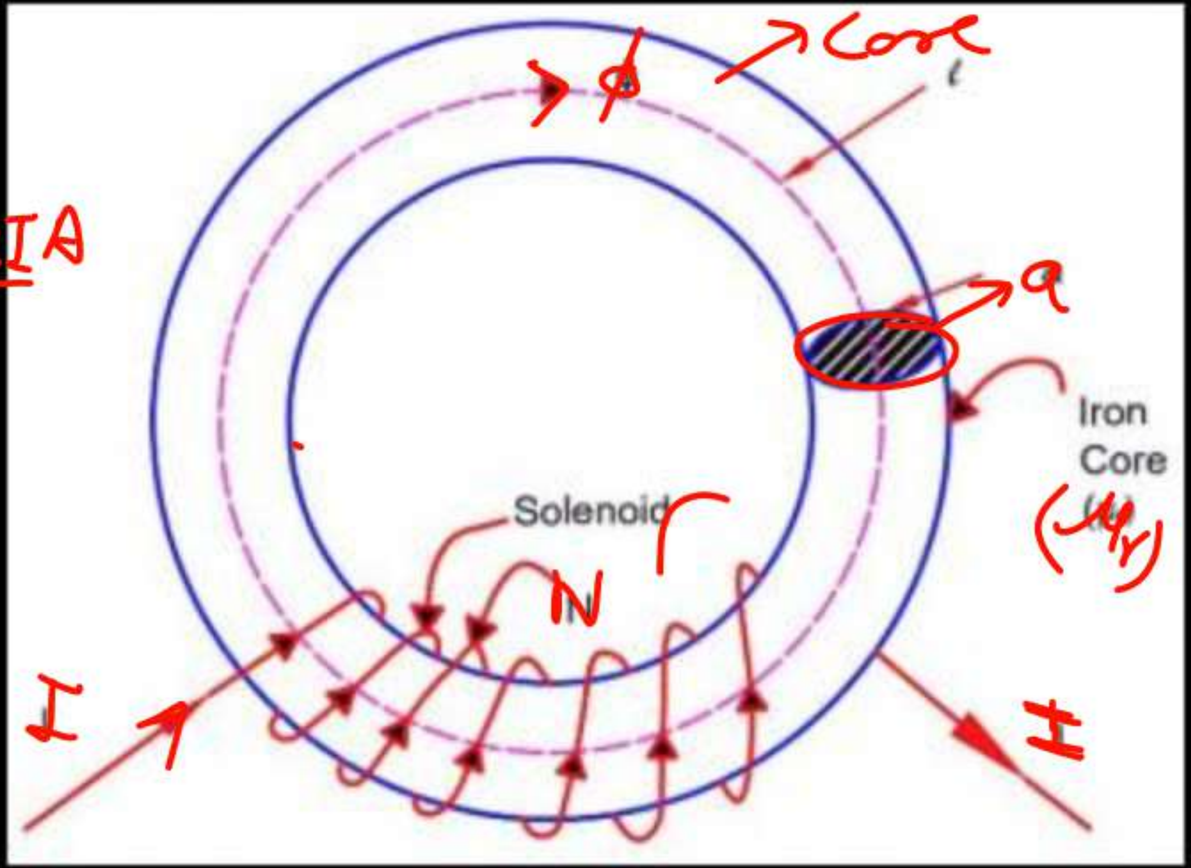
$= \frac{\frac{NI}{l}}{A\mu_0\mu_r}$

The denominator $\frac{l}{A\mu_o\mu_r}$ is called reluctance of the circuit

and NI is called mmf .

$$\emptyset = \frac{mmf}{reluctance} \text{Wb}$$

this relation is similar to electric circuit I = V/R



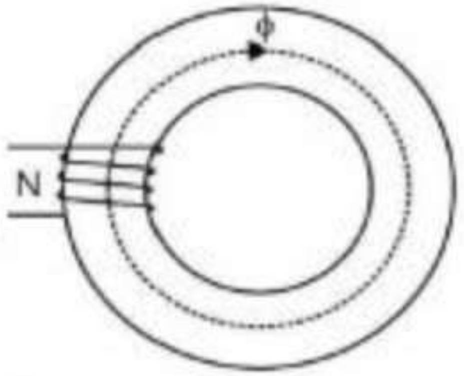
Similarities between Magnetic Circuit & Electric Circuit

Similarities

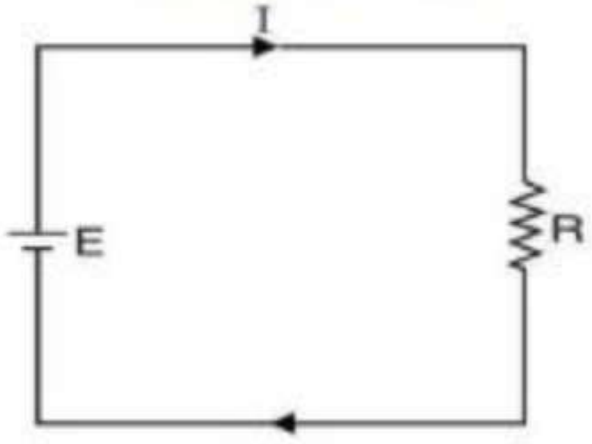
Analogous

1. The closed path for magnetic flux is called a magnetic circuit.	1. The closed path for electric current is called an electric circuit.
2. Flux, $\phi = \frac{\text{m.m.f.}}{\text{reluctance}}$	2. Current, $I = \frac{\text{e.m.f.}}{\text{resistance}}$
3. m.m.f. (ampere-turns)	3. e.m.f. (volts)
4. Reluctance, $S = \frac{l}{a\mu_0\mu_r}$	4. Resistance, $R = \rho \frac{l}{a}$
5. Flux density, $B = \frac{\phi}{a}$ Wb/m^2	5. Current density, $J = \frac{I}{a}$ A/m^2
6. m.m.f. drop $= \phi S$	6. Voltage drop $= I R$
7. Magnetic intensity, $H = N I / l$	7. Electric intensity, $E = V / d$
8. Permeance	8. Conductance.
9. Permeability	9. Conductivity

Magnetic Circuit



Electric Circuit



Disimilarities between Magnetic Circuit & Electric Circuit

Dissimilarities

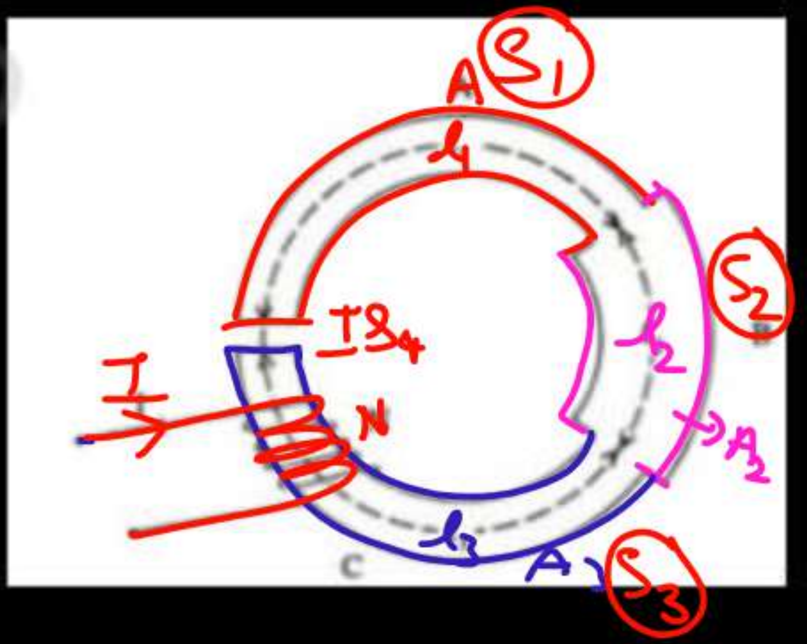
1. Truly speaking, magnetic flux does not flow. flux is setup in the Core.	1. The electric current acutally flows in an electric circuit. I=0
2. There is no magnetic insulator. For example, flux can be set up even in air (the best known magnetic insulator) with reasonable m.m.f.	2. There are a number of electric insulators. For instance, air is a very good insulator and current cannot pass through it.
3. The value of μ_r is not constant for a given magnetic material. It varies considerably with flux density (B) in the material. This implies that reluctance of a magnetic circuit is not constant rather it depends upon B.	3. The value of resistivity (ρ) varies very slightly with temperature. Therefore, the resistance of an electric circuit is practically constant. This salient feature calls for different approach to the solution of magnetic and electric circuits.
4. No energy is expended in a magnetic circuit. In other words, energy is required in creating the flux, and not in maintaining it.	4. When current flows through an electric circuit, energy is expended so long as the current flows. The expended energy is dissipated in the form of heat.

~~Alternating Quantity~~

"Series Magnetic Circuit"

- ***Series magnetic circuits*** **:-** consider a circular ring made from different materials of lengths l_1, l_2 *and* l_3 ,cross-sectional areas a_1, a_2 *and* a_3 and relative permeability μ_{r1}, μ_{r2} *and* μ_{r3} respectively with a cut of length lg called air gap. The total reluctance is the arithmetic sum of individual reluctance as they are joined in series.

$$S = \frac{1}{\mu} \cdot \frac{l}{a}$$



$$Total\ reluctance(S) = \frac{l_1}{\mu_0\mu_{r1}a_1} + \frac{l_2}{\mu_0\mu_{r2}a_2} + \frac{l_3}{\mu_0\mu_{r3}a_3} + \frac{l_g}{\mu_0 a_g}$$

$$\mu_r = 1$$

$$\frac{l_1}{\mu_0\mu_r A_1} + \ldots$$

$$Total\ mmf = \phi \times S$$

$$= \phi\left[\frac{l_1}{\mu_0\mu_{r1}a_1} + \frac{l_2}{\mu_0\mu_{r2}a_2} + \frac{l_3}{\mu_0\mu_{r3}a_3} + \frac{l_g}{\mu_0 a_g}\right]$$

$$or\ Total\ ampere - turns\ required$$

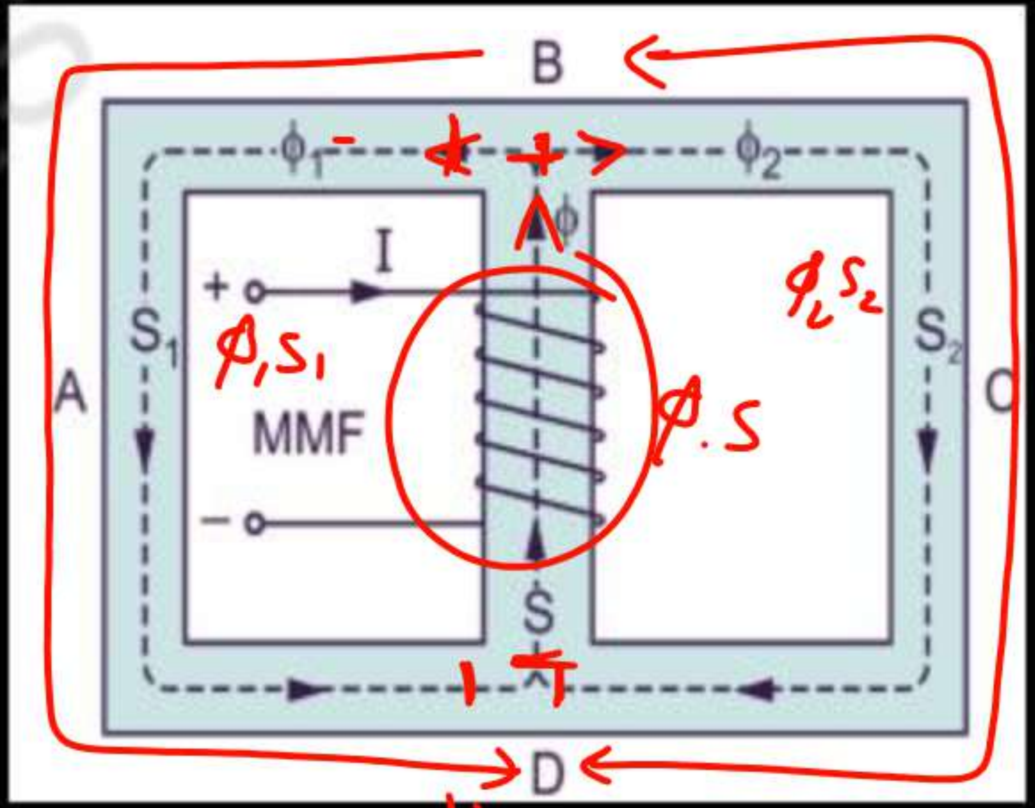
$$= \boxed{H_1 l_1 + H_2 l_2 + H_3 l_3 + H_g l_g}$$

(Parallel Magnetic Ckt)

A magnetic circuit which has more one path for the magnetic flux is called as ***parallel magnetic circuit.***

Consider a coil of N turns wound on limb BD carries an electric current of I amperes. The magnetic flux ϕ set up by the coil divides at B into two paths. The magnetic ϕ_2 passes along the path BCD. The magnetic flux ϕ_1 passes along the path BAD.

Therefore, the total flux is, $\Phi = \phi_1 + \phi_2$



The path BD and BCD are in parallel and hence form a parallel magnetic circuit. In a parallel magnetic circuit, the MMF required for the whole parallel magnetic circuit is equal to MMF required for any one of the parallel paths.

Let

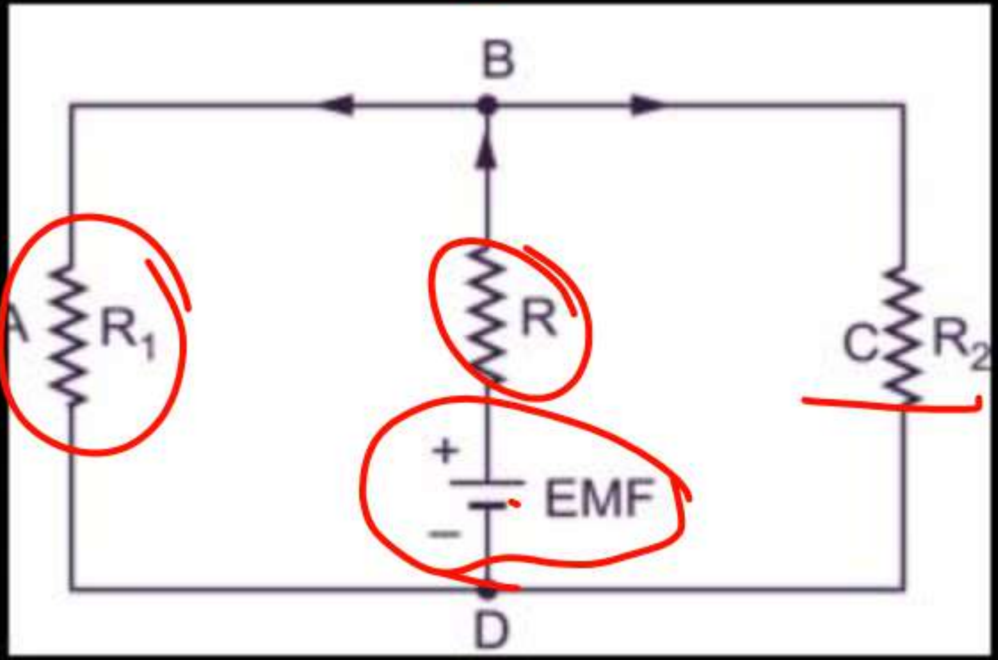
S = Reluctance of magnetic path BD, S_1 = Reluctance of magnetic path BAD

S_2 = Reluctance of magnetic path BCD

Therefore,

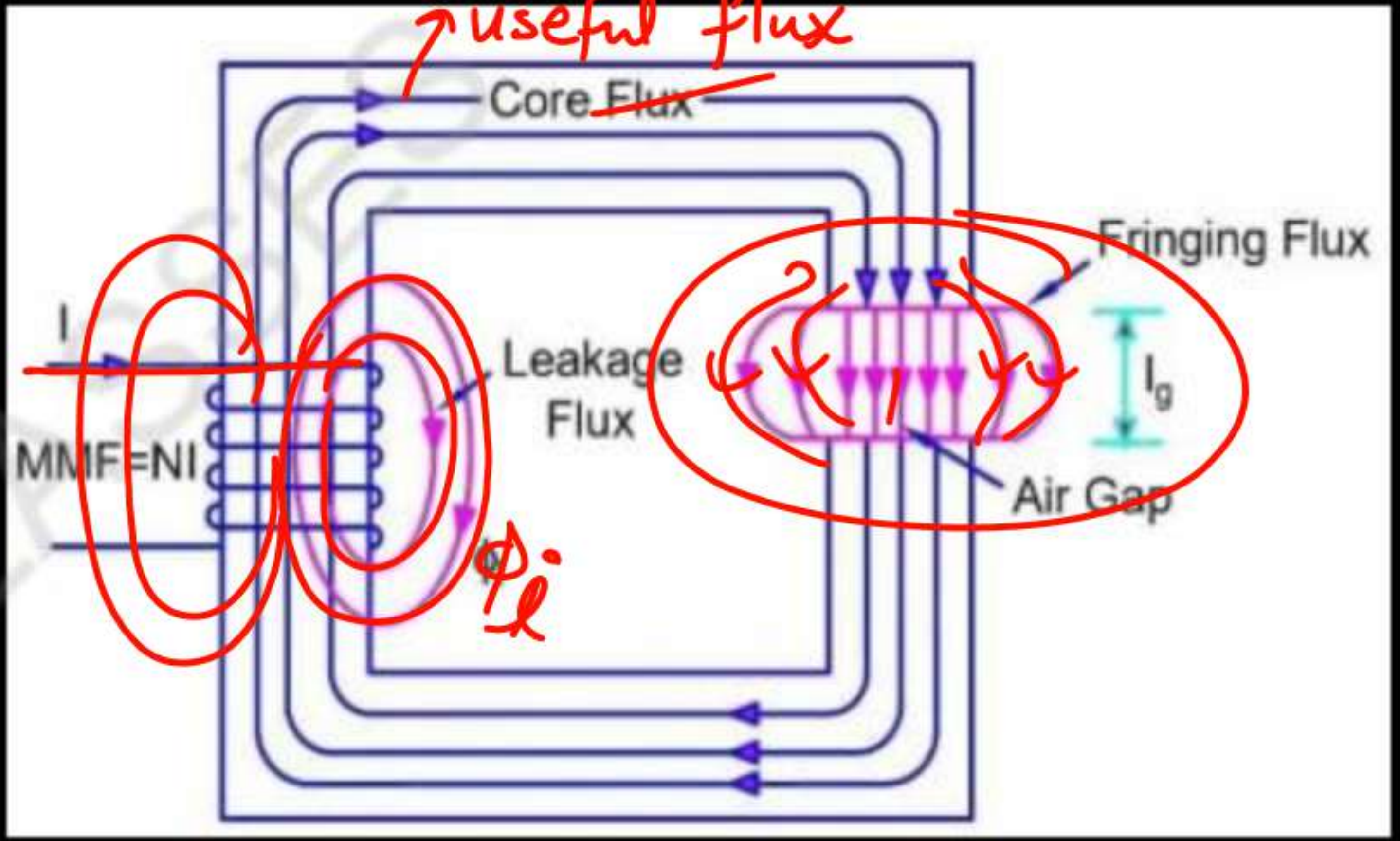
Total MMF=MMF for path ABD+MMF for path BD or BCD

$$MMF = \phi . S + \phi_2 . S_2 = \phi . S + \phi_1 . S_1$$



Leakage Flux and Fringing

Leakage Flux:- The part of magnetic flux that does not follow the desired path in a magnetic circuit is known as *leakage flux.*



Flux can be divided into two main components

(i) magnetic flux throughout the magnetic circuit including air gap is known as ***useful flux* (ϕg)**

(ii) leakage flux *Link partially with magnetic circuit and complete its path through air.*

Leakage Flux = Total flux- useful flux

$$\Phi_{leakage} = \Phi_i - \Phi_g$$

$$\text{Leakage Coefficient, } \lambda = \frac{\text{Total Magnetic Flux } (\phi i)}{\text{Useful Magnetic Flux } (\phi g)}$$

Magnetic Fringing:- When the magnetic field lines pass through an air gap, they tend to bulge out . It is because the magnetic field lines repel each other when passing through the air . This effect is known as *magnetic fringing.*

Due to magnetic fringing, the effective area of the air gap is increased and thus the magnetic flux density is decreased in the air gap. The longer the air gap, the higher is the fringing and *vice-versa*.

Numerical Examples Magnetic Circuit

Ex.-1 :- A coil of 1000 turns is wound uniformly on an iron ring of mean circumference 50 cm and across sectional area 5 cm2 . Current 12 Amp is flowing through coil. Relative permeability of the material is 4000. Find (i) MMF (ii) Total flux (iii) Reluctance. 2019-20

$N = 1000$, $l = 50\,cm$

$a = 5\,cm^2$, $I = 12\,amp$

$\mu_r = 4000$

$mmf = NI = 1000 \times 12 = 12000\,AT$

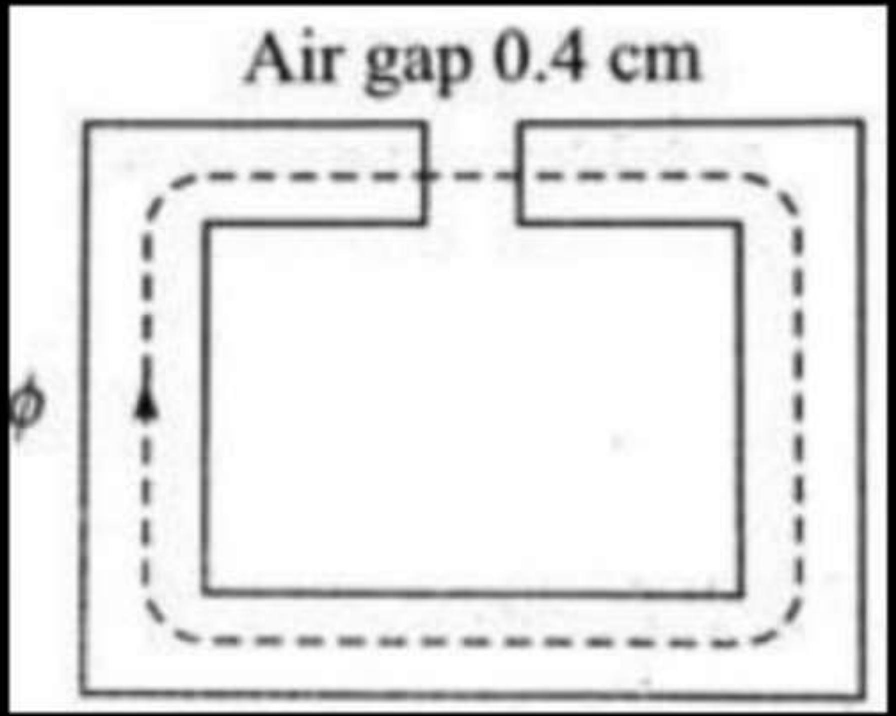
$\phi = \frac{mmf}{S} = \frac{12000}{1.98\times10^5} = 0.06\,wb.$

$S = \frac{l}{a\mu_0\mu_r} = \frac{50\times10^{-2}}{5\times10^{-4}\times4\pi\times10^{-7}\times4000} = 1.98\times10^5$

As

Basic Definitions

Ex-2 An electromagnet is shown in figure whose area of cross section is 12cm2 . Mean length of iron path is 50cm. It is excited by two coils each having 400 turns. When the current in the coil is 1.0 A, the resulting flux density gives a relative permeability of 1300. Calculate (i) reluctance of iron part, air gap and total reluctance.(ii) total flux(iii) flux density in air gap. 2018-19



$a = 12\ cm^2,\ l_i = 50\,cm$

$N = 2 \times 400 = 800$

$I = 1\,A,\ \mu_r = 1300$

$S_i = \dfrac{l_i}{a_i \cdot \mu_0 \cdot \mu_r} = \dfrac{0.5}{12\times10^{-4} \times 4\pi\times10^{-7} \times 1300}$

$\boxed{S_i = 2.55\times10^5}$

$S_g = \dfrac{0.4\times10^{-2}}{12\times10^{-4} \times 4\pi\times10^{-7}}$

$= 2.65\times10^5$

Total $S = S_i + S_g$

$\boxed{S = 5.20\times10^5}$

$\phi = \dfrac{mmf}{S} = \dfrac{NI}{S}$

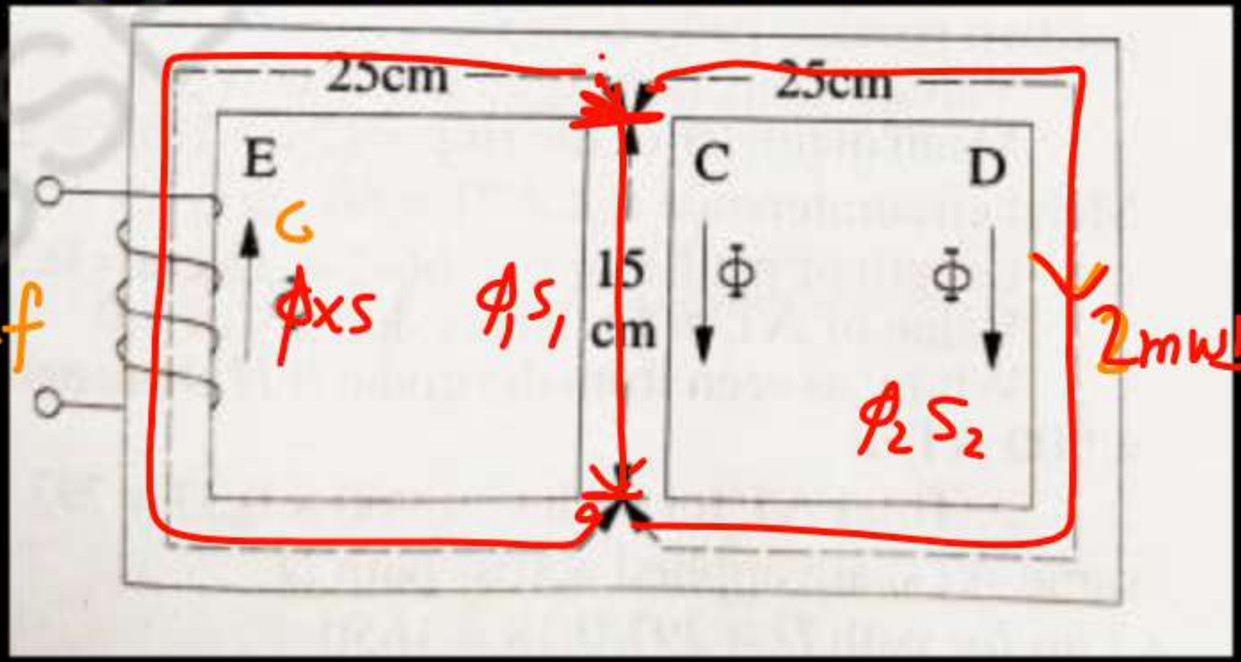
$= \dfrac{800\times1}{5.2\times10^5} = 1.5\,mwb.$

$B = \dfrac{\phi}{A} = \dfrac{1.5\,mwb}{12\times10^{-4}}$

$= 1.25\times10 = 12.5$

Numerical Examples Magnetic Circuit

- Ex. 3 :- A cast steel magnetic structure made of a bar 0f section 8cm x 2 cm is shown in figure . Determine the current that the 500 turn magnetizing coil on the left limb should carry so that a flux of 2 m Wb is produced in the right limb. Take μr= 600 and neglect leakage.



$a = 16\,cm^2,\ N = 500$

$\mu_r = 600,\ I = ?$

$\phi_1 S_1 = \phi_2 S_2$

$\phi_1 = \phi_2 \dfrac{S_2}{S_1}$

$= \dfrac{\dfrac{l_2}{\cancel{a_2 \mu_0 \mu_r}}}{\dfrac{l_1}{\cancel{a_1 \mu_0 \mu_r}}}$

$\phi_1 = \phi_2 \dfrac{l_2}{l_1} = \dfrac{2\times10^{-3} \times \cancel{25}\times\cancel{10^{-2}}}{\cancel{15}\times\cancel{10^{-2}}}$ 3

$\phi = \dfrac{10}{3}\times10^{-3} = 3.33\times10^{-3}$

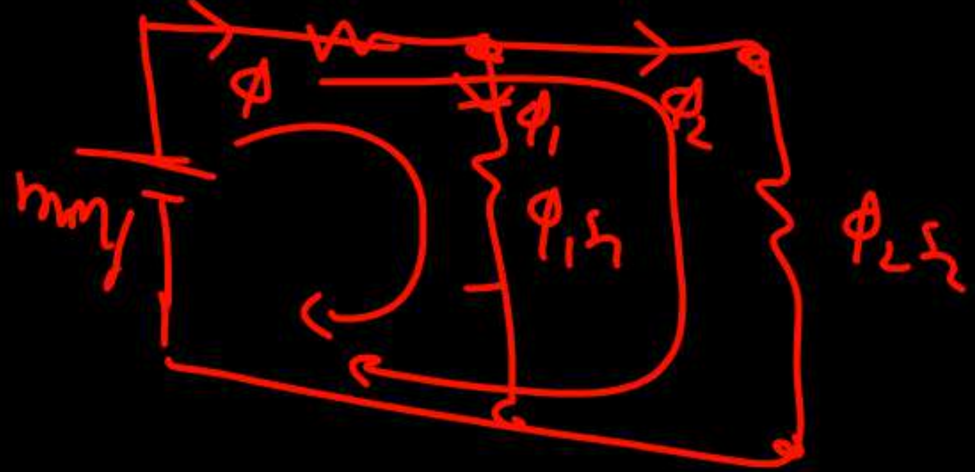
$\phi = \phi_1 + \phi_2 = 2 + 3.33 = 5.33\,mwb$

$mmf = \phi . S + \phi_1 S_1$

$= 5.33\times10^{-3}\left(\dfrac{l}{a\mu_0\mu_r}\right) + 3.33\times10^{-3}\left(\dfrac{l_1}{a_1\mu_0\mu_r}\right)$

$NI = 1508.65$

$I = \dfrac{1508.65}{500}$ Ans



Faraday's law of Electromagnetic Induction

First law: Whenever a conductor is placed in a varying magnetic field, EMF induces and this emf is called an induced emf and if the conductor is a closed circuit than the induced current flows through it.

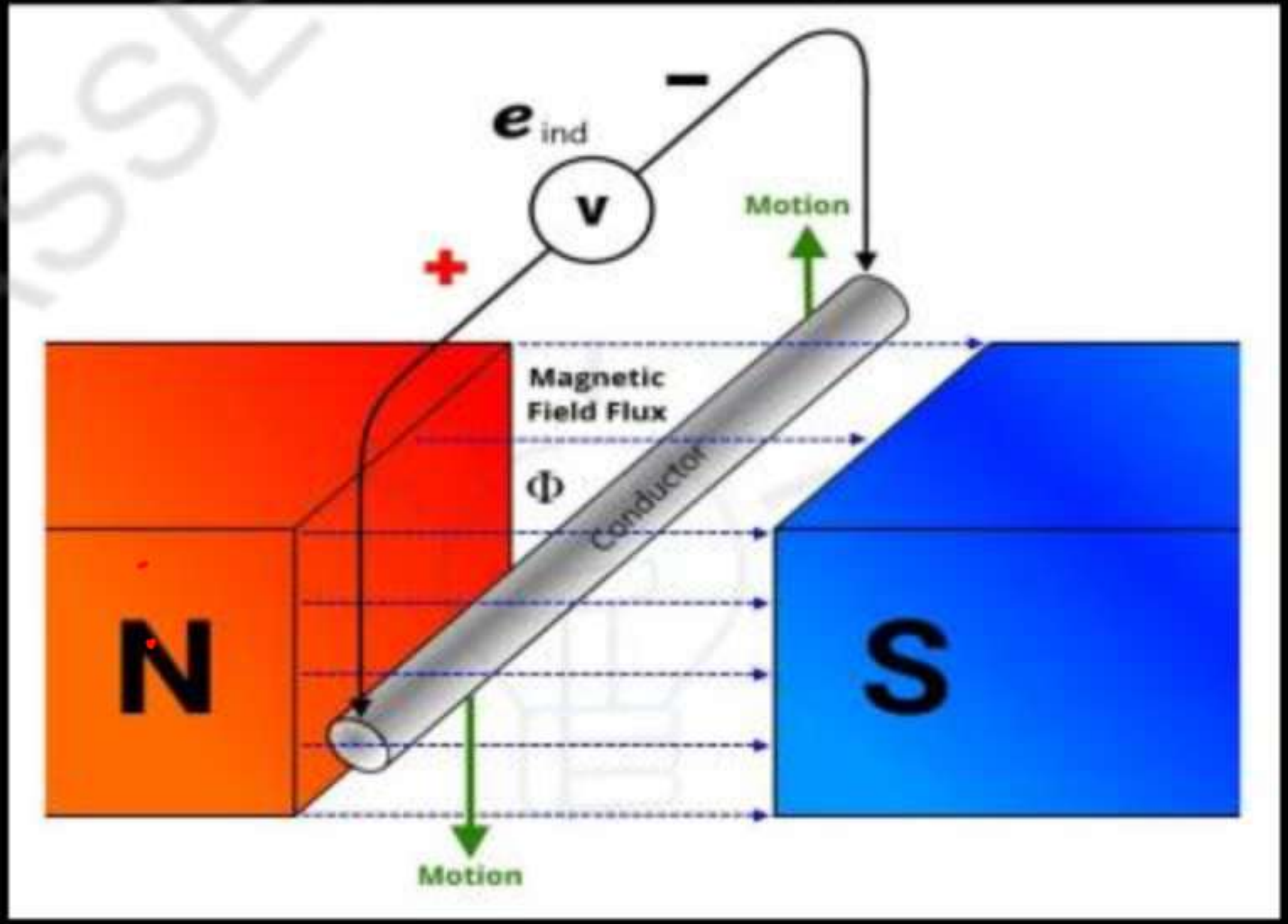
Second law: The magnitude of the induced EMF is equal to the rate of change of flux linkages.

Based on his experiments we now have Faraday's law of electromagnetic induction according to which the amount of voltage induced in a coil is proportional to the number of turns and the changing magnetic field of the coil.

So now, the induced voltage is as follows:

$$\boxed{e = N \times d\Phi / dt}$$

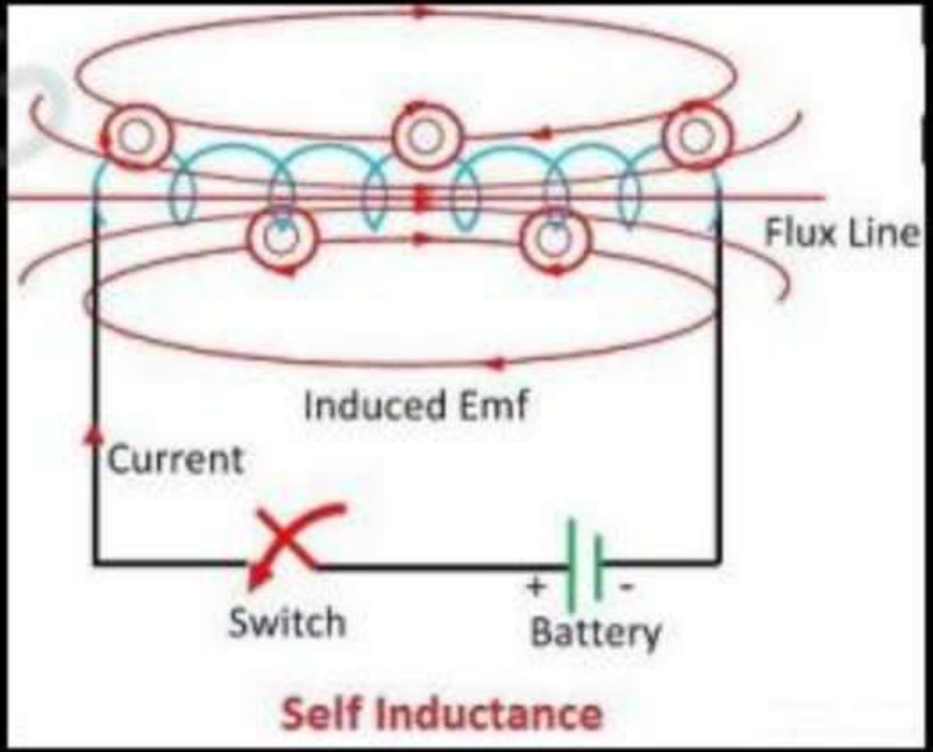
Faraday's Laws of Electromagnetic Induction



Self and mutual Inductance

Self-inductance :- It is defined as the property of the coil due to which it opposes the change of current flowing through it. Inductance is attained by a coil due to the self-induced emf produced in the coil itself by changing the current flowing through it.

If the current in the coil is increasing, the self-induced emf produced in the coil will oppose the rise of current, that means the direction of the induced emf is opposite to the applied voltage

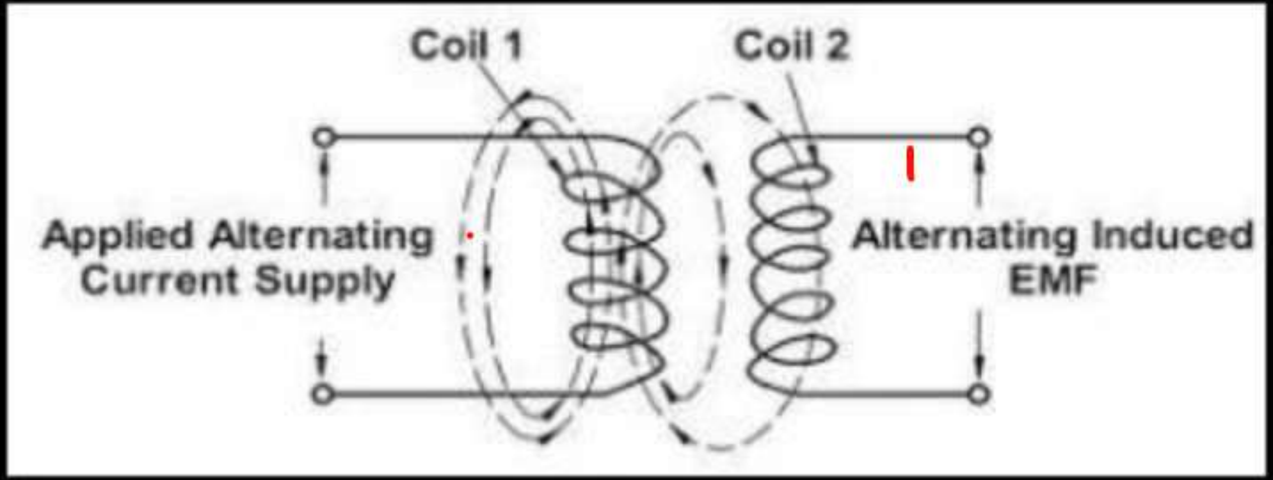


$$e = L\frac{dI}{dt}$$

$$L = \frac{e}{dI/dt}$$

Mutual Inductance between the two coils is defined as the property of the coil due to which it opposes the change of current in the other coil, or you can say in the neighboring coil.

When the current in the neighboring coil changes, the flux sets up in the coil and because of this, changing flux emf is induced in the coil called Mutually Induced emf and the phenomenon is known as **Mutual Inductance.**



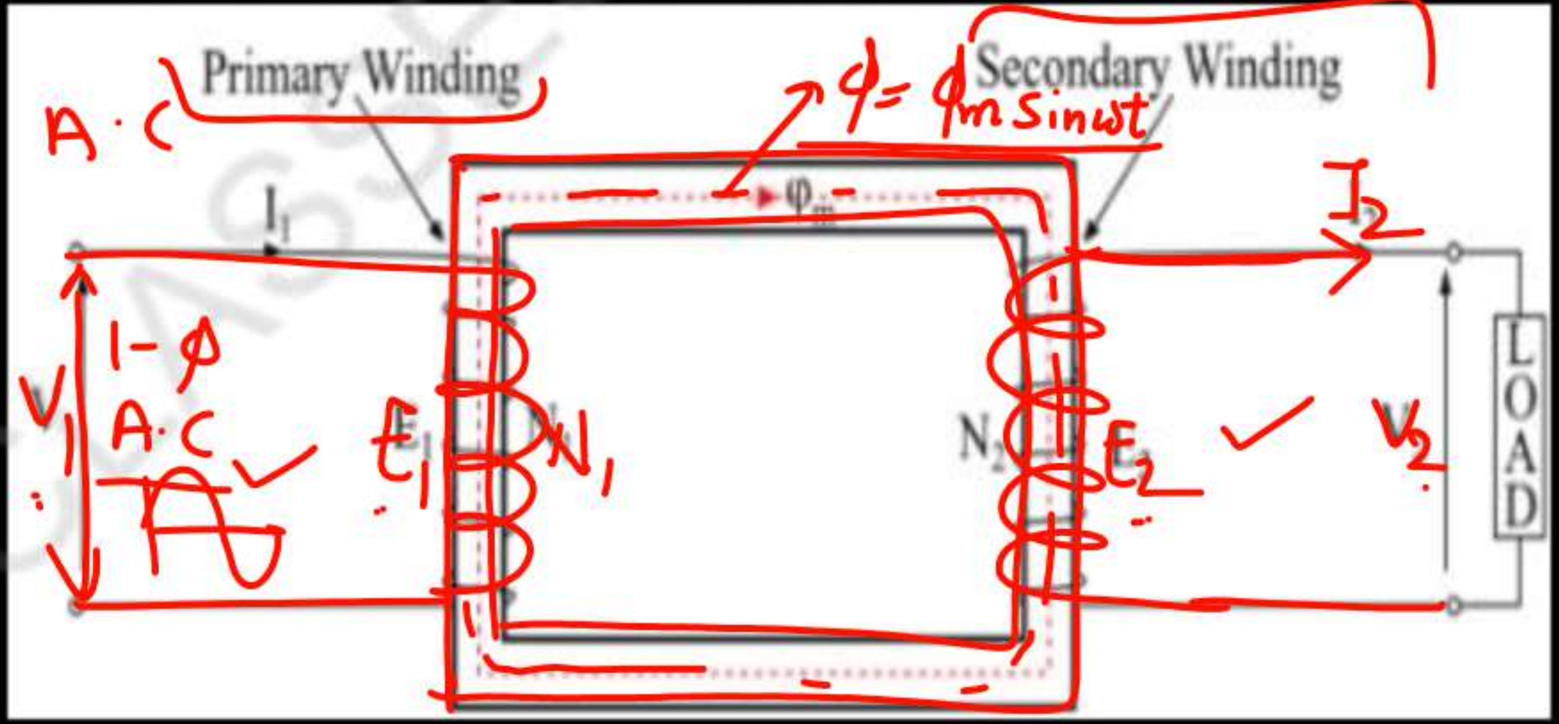
$$e_m = M\frac{dI_1}{dt}$$

$$M = \frac{e_m}{dI_1/dt} \quad \text{..........(1)}$$

Transformer

A *transformer* is a static electrical machine which is used for either increasing or decreasing the voltage level of the AC supply with a corresponding decrease or increase in the current at constant frequency.

Working Principle of Transformer



- The **basic principle behind working of a transformer** is the phenomenon of mutual induction between two windings linked by common magnetic flux.
- Transformer consists of two inductive coils; primary winding and secondary winding.
- When, primary winding is connected to a source of alternating voltage, alternating magnetic flux is produced around the winding.
- The core provides magnetic path for the flux, to get linked with the secondary winding.
- As the flux produced is alternating, EMF gets induced in the secondary winding according to Faraday's law of electromagnetic induction.
- This emf is called 'mutually induced emf', and the frequency of mutually induced emf is same as that of supplied emf.
- If the secondary winding is closed circuit, then mutually induced current flows through it, and hence the electrical energy is transferred from one circuit (primary) to another circuit (secondary).

Transformer (Turns Ratio)

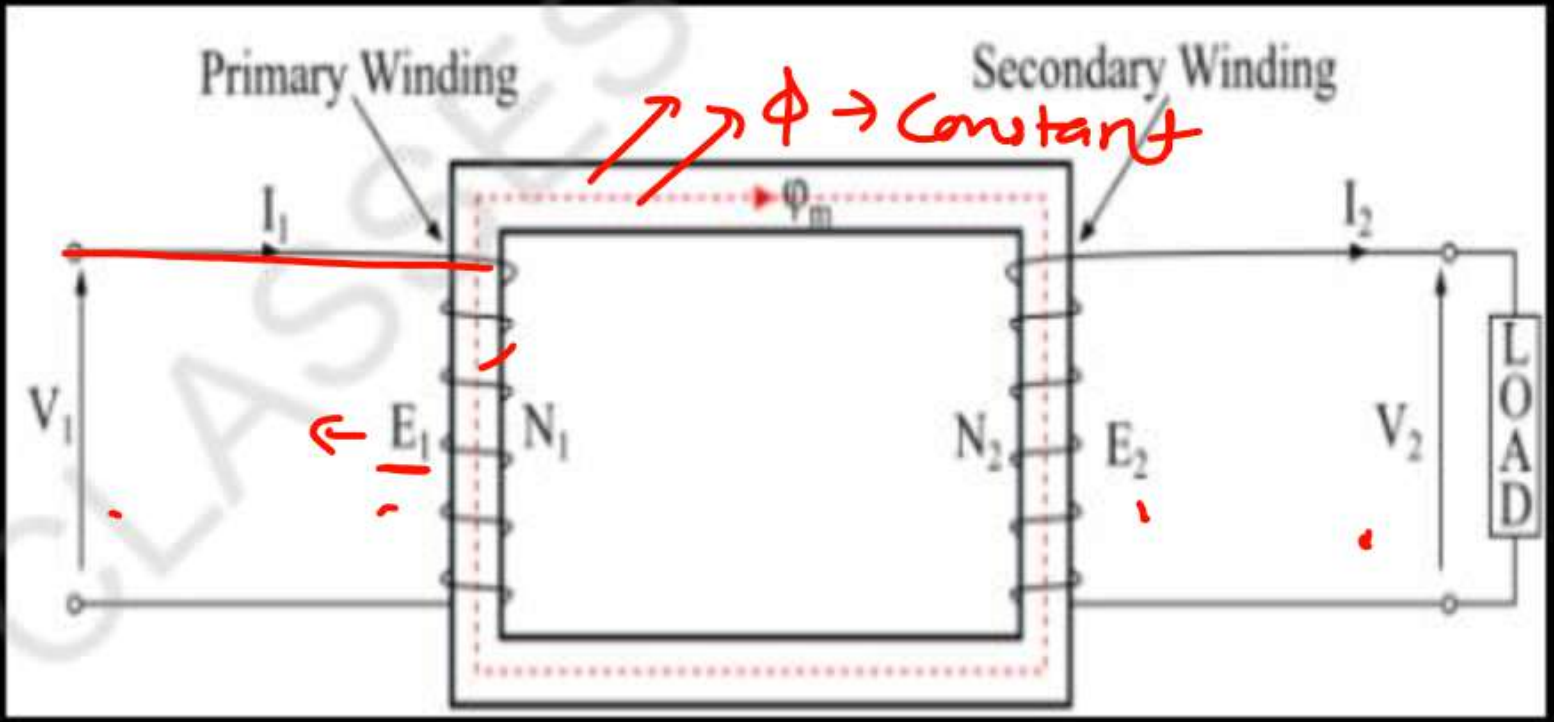
$E_1 = -N_1\, d\phi_m / dt$
and
$E_2 = -N_2\, d\phi_m / dt$

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = K$$

$$K = \frac{I_1}{I_2} = \frac{N_2}{N_1}, \frac{V_2}{V_1}, \frac{E_2}{E_1}$$

Therefore

$E_2 / E_1 = N_2 / N_1$



ϕ = Constant

$\boxed{E = 0}$

Transformer will not work.

Imp 2 mark

Can Transformer work on DC

No

Types Of Transformers

Transformers can be classified on different basis, like types of construction, types of cooling etc.

On the basis of construction

→ Core type

→ Shell type

On the basis of their purpose

→ Step up $V_2 > V_1$

→ step down $V_2 < V_1$

On the basis of type of supply

→ $1-\phi$

$3-\phi$

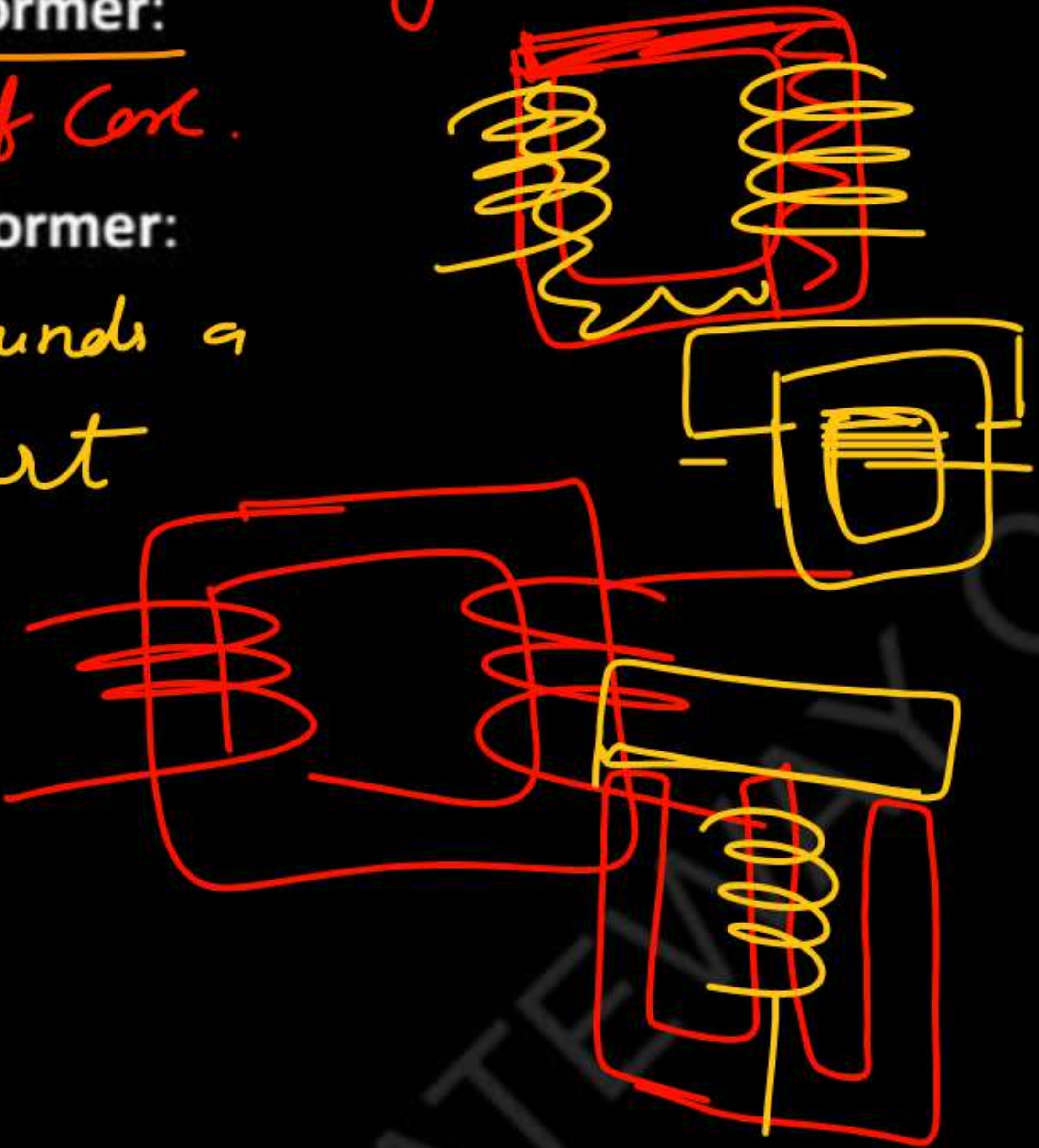
Classification of Transformer based on Construction

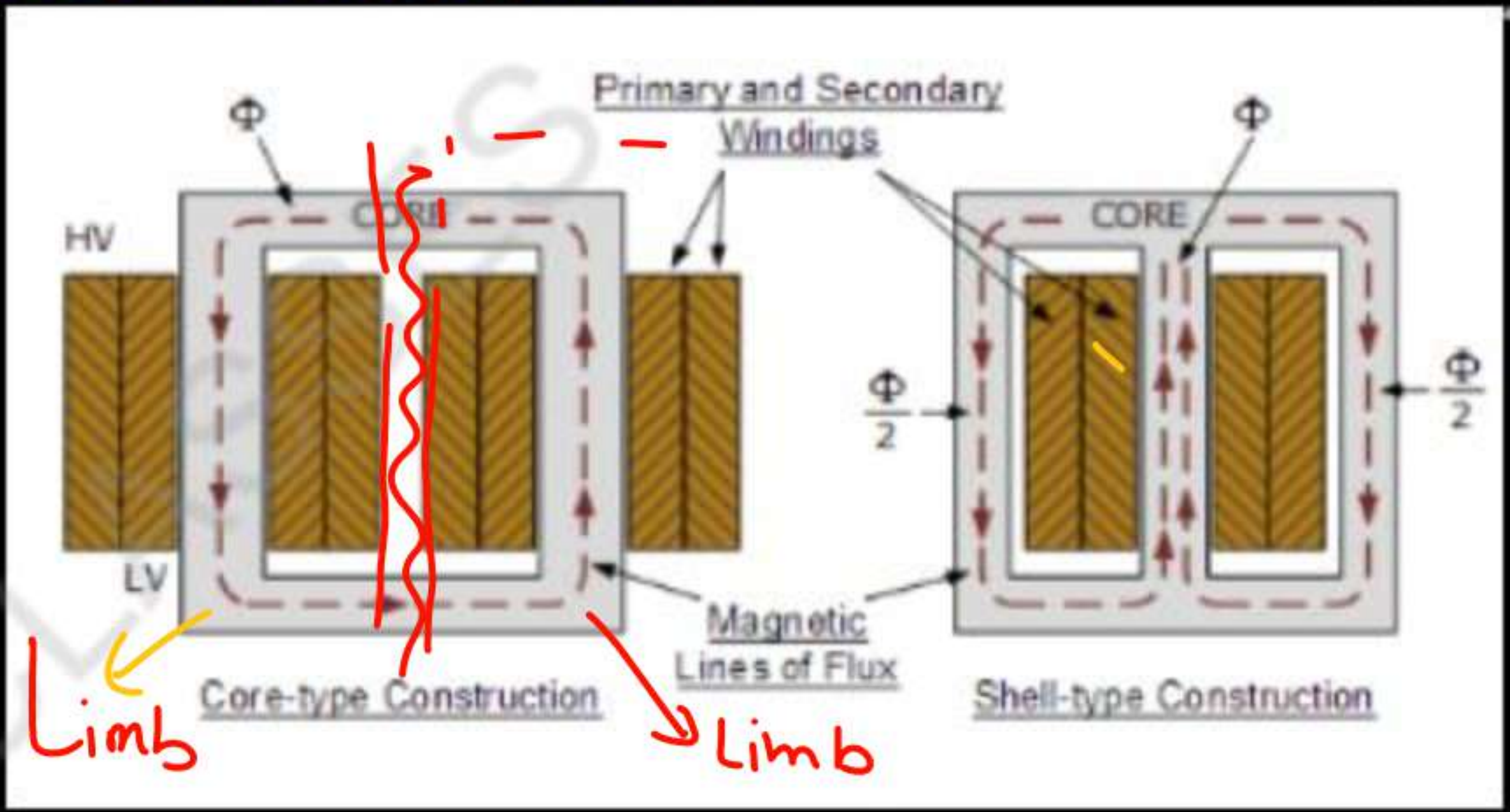
- 1. **Core type transformer:** winding surrounds a

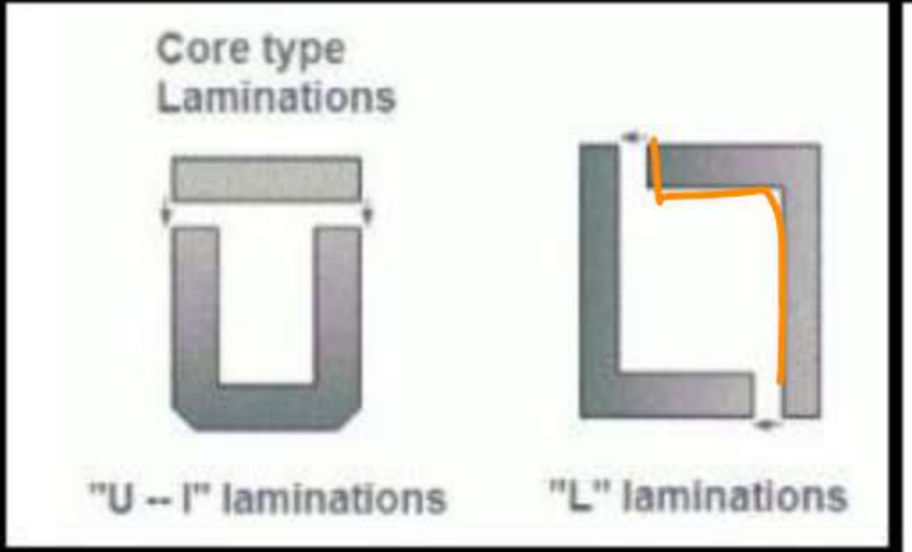
Considerable Part of Core.

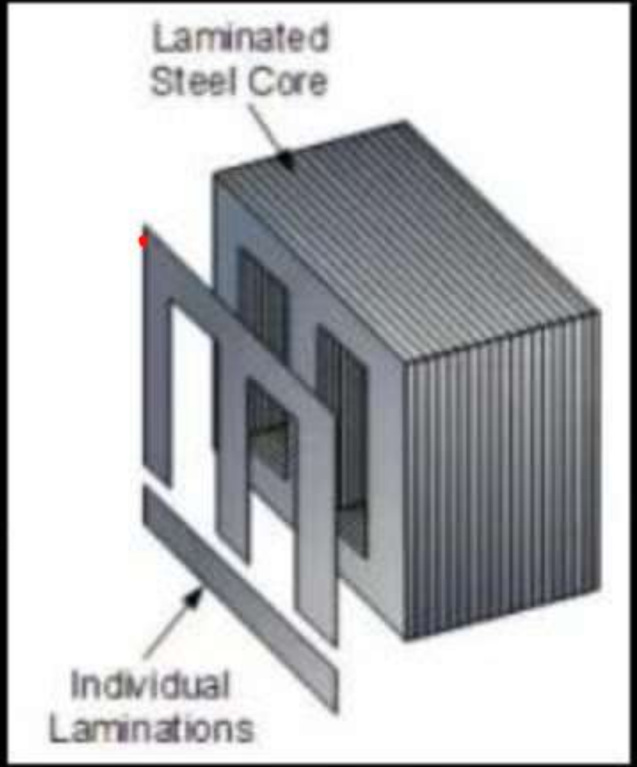
- 2. **Shell-type transformer:**

Core surrounds a considerable part of winding.









E.M.F. Equation of Transformer

$$\phi = \phi_m \sin\omega t$$

E.m.f induced

$$E_1 = -N_1 \frac{d\phi}{dt}$$

$$= -N_1 \frac{d}{dt}(\phi_m \sin\omega t)$$

$$= -N_1 \phi_m \omega \cos\omega t$$

$$e_1 = \underline{-N_1 \phi_m \omega} \sin\left(\omega t - \frac{\pi}{2}\right)$$

$$E_1 = \underline{E_m} \sin\omega t$$ → standard Equation

on Comparing

$$E_m = N_1 \phi_m \omega$$

$$E_{1rms} = \frac{E_m}{\sqrt{2}}$$

$$E_1 = \frac{N_1 \phi_m \omega}{\sqrt{2}}$$

$$= \frac{N_1 \phi_m 2\pi f}{\sqrt{2}}$$

$$E_1 = N_1 \phi_m f . \sqrt{2}\pi$$

$$\boxed{E_1 = 4.44 N_1 \phi_m f}$$

$$\boxed{E_2 = 4.44 N_2 \phi_m f}$$

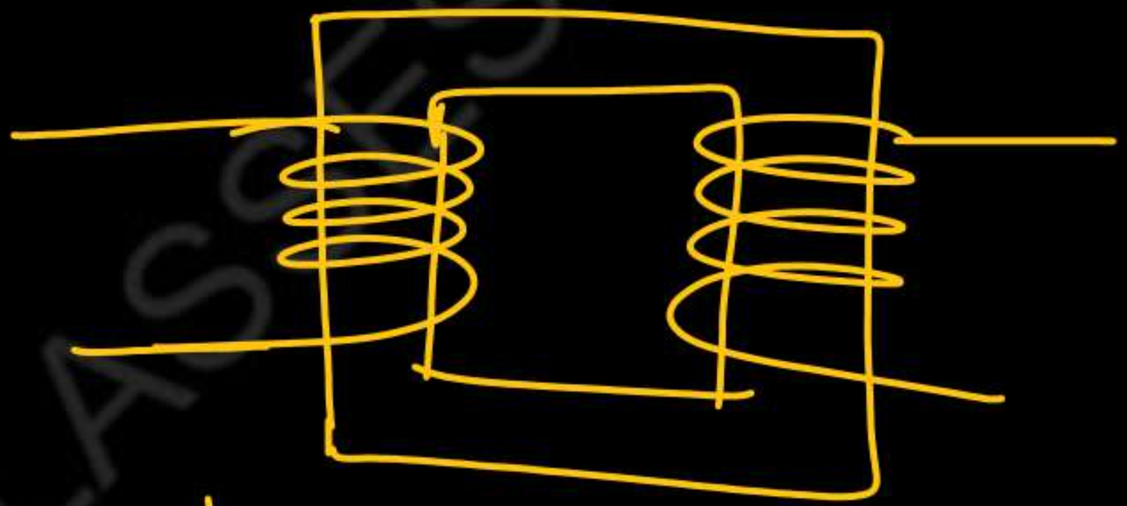
Rating of Transformer

→ Core loss → $\propto V$ Volt

→ Copper loss → I — Amp

$$\boxed{\text{Rating} = KVA}$$

Ideal and Practical Transformer



Losses = 0

Ideal

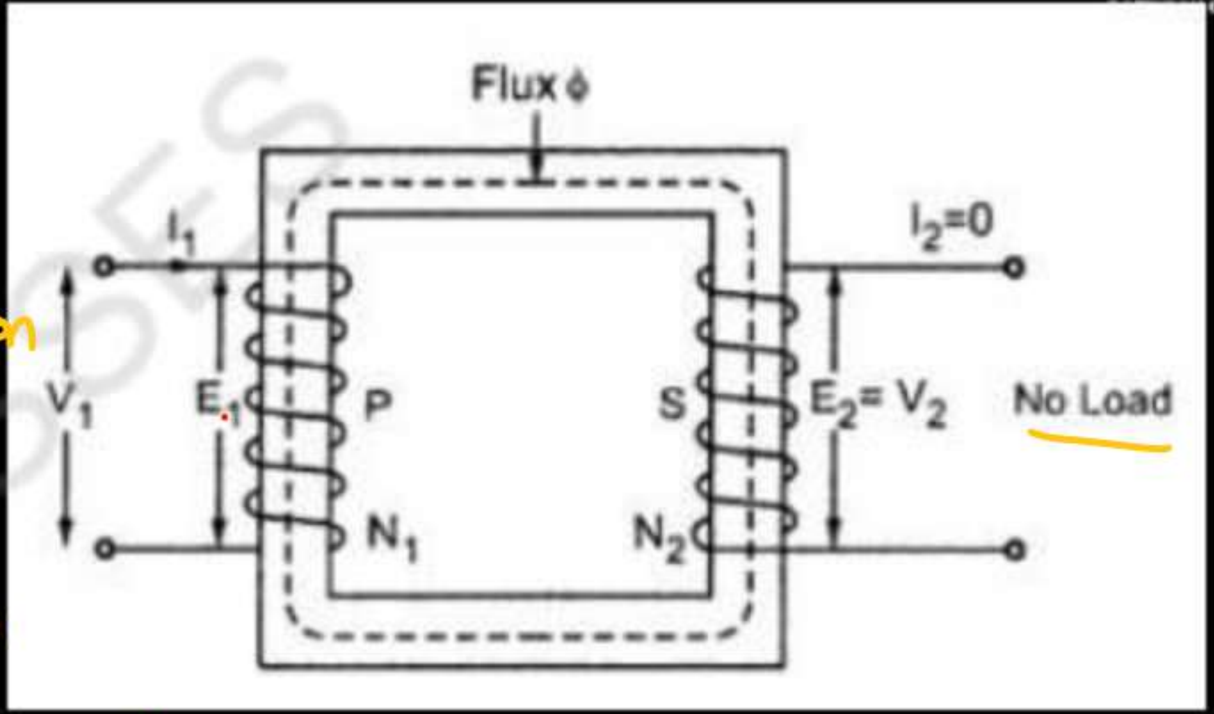
Practical

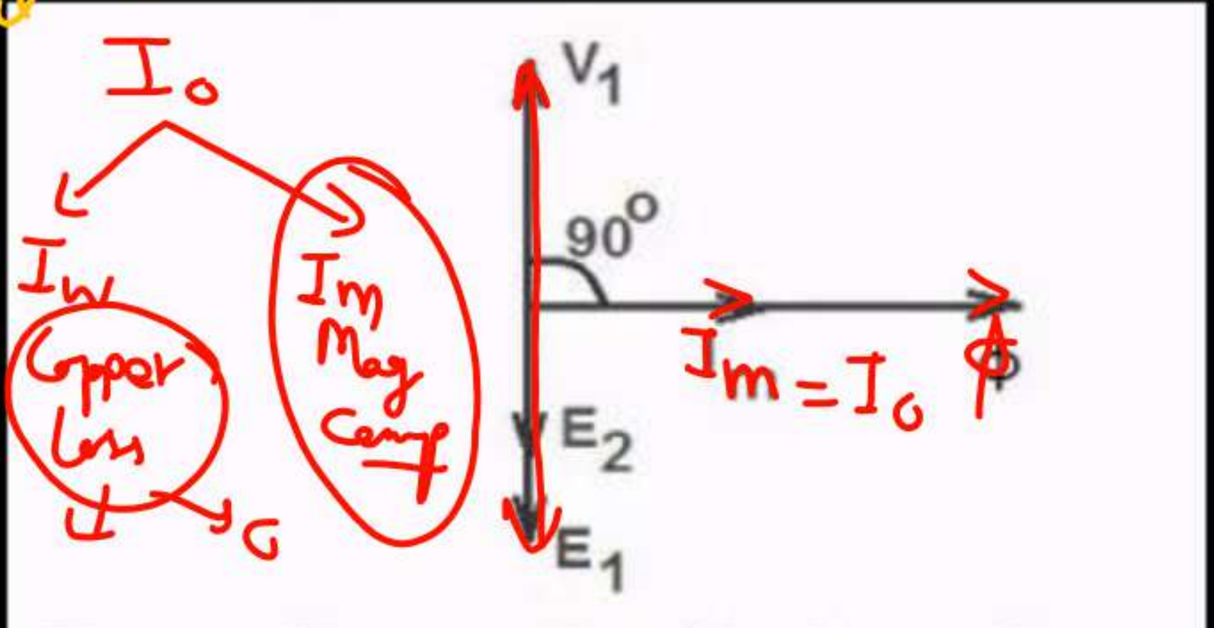
Losses → ✓

Ideal Transformer on no load

- The primary draws a very small current I_1 which is just necessary to produce flux in the core. As it is magnetizing the core, it is called **magnetizing current denoted as I_m.**
- As the transformer is ideal, the winding reactance is zero and it is purely inductive in nature.
- The magnetizing current is very small and lags V_1 by 90° as the winding is purely inductive. This I_m produces an alternating flux Φ which is in phase with I_m.
- The flux links with both the winding producing the induced emf E1 and E2, in the primary and secondary windings respectively.
- According to Lenz's law, the induced emf opposes the cause producing it which is supply voltage V1. Hence E1 is in antiphase with V1 but equal in magnitude.
- The induced emf E2 also opposes V1 hence in antiphase with V1 but its magnitude depends on N2. Thus E1 and E2 are in phase.

No Load Current → I_m, I_W → ideal = 0





Phasor diagram of an ideal transformer

Practical Transformer on no load

GW GATEWAY CLASSES

The no-load current consists of two components:

Reactive or magnetizing component Im:- It produces flux in the core

Active or power component I_w:- It supplies small amount of primary copper loss.

Hence the primary no load current I_0 is not 90° behind the applied voltage V_1 but lags it by an angle Φ_0 < 90° as shown in the phasor diagram.

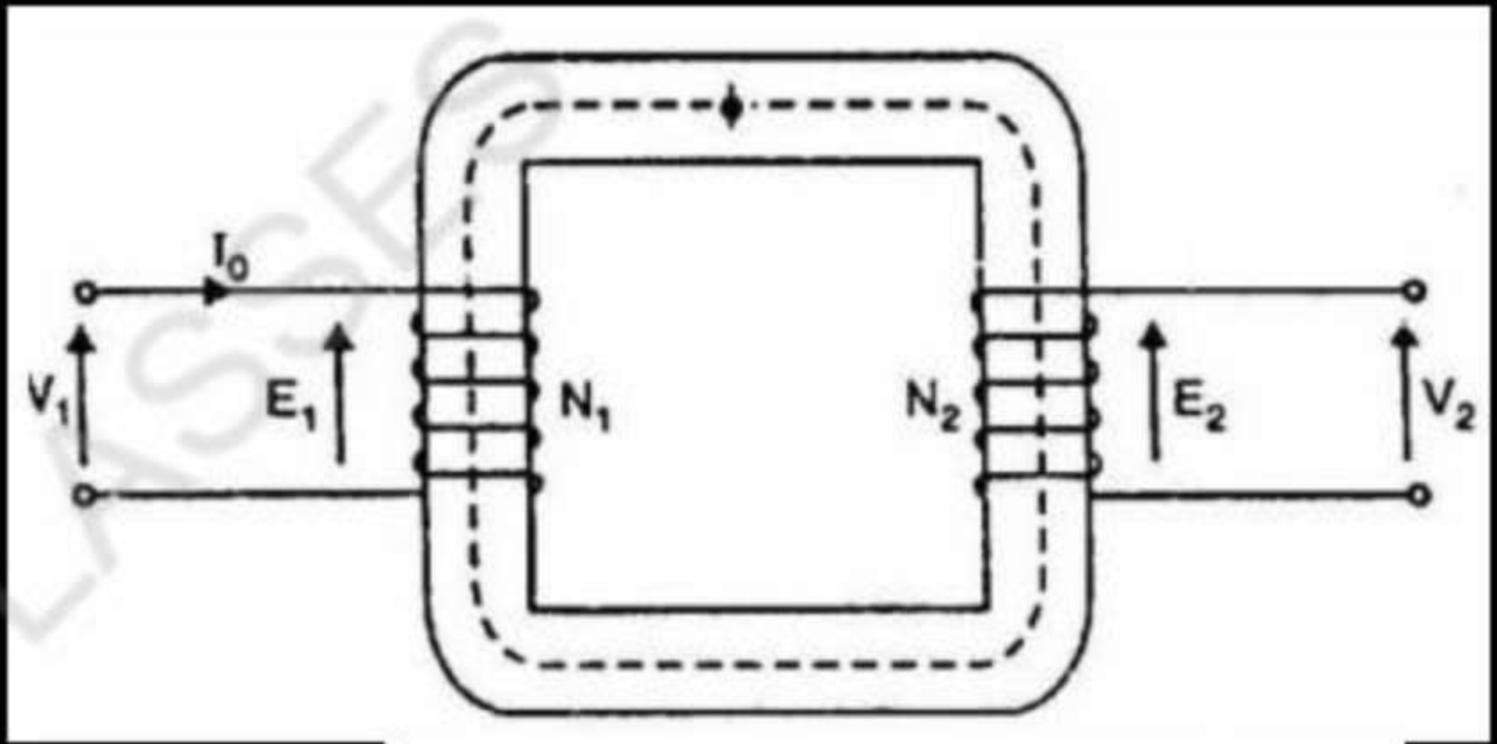
Working component $I_w = I_0 \cos\varphi_0$

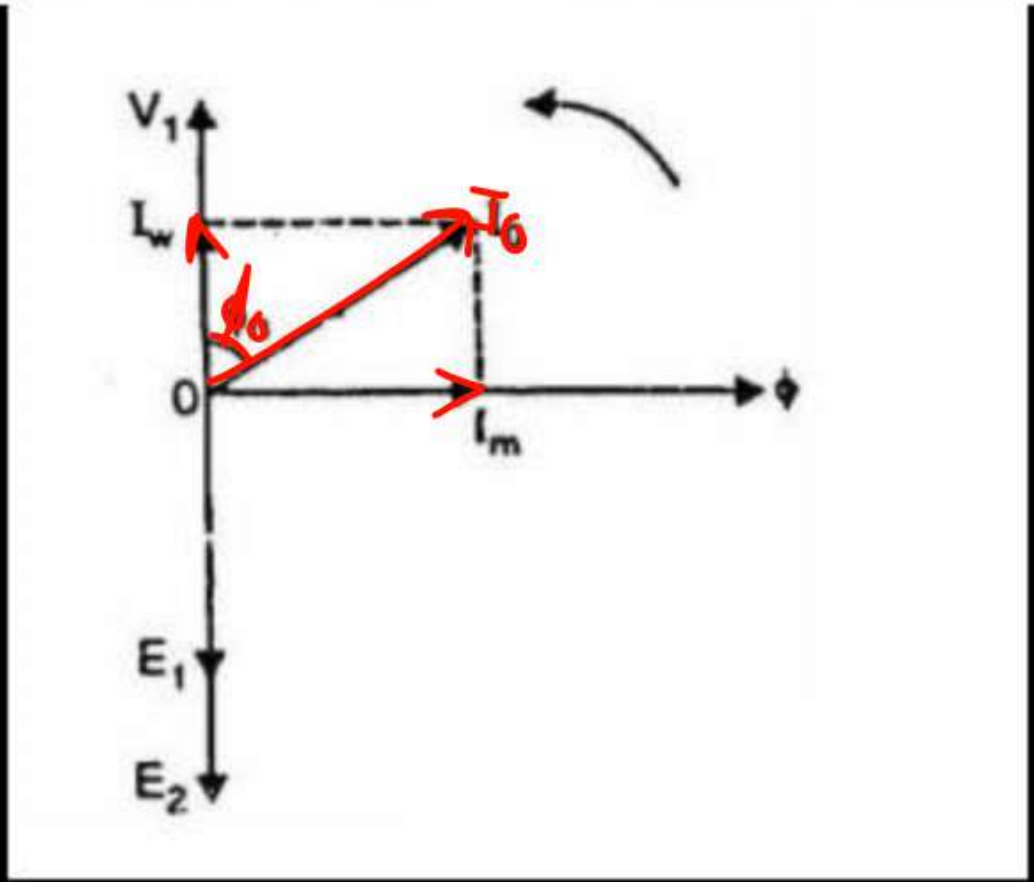
No load current $I_0 = \sqrt{I_w^2 + I_m^2}$

Magnetizing component $I_m = I_0 \sin\varphi_0$

Power factor $\cos\varphi_0 = \dfrac{I_w}{I_0}$

No load power input $P_0 = V_1 I_0 \cos\varphi_0$





Practical Transformer on no load

Ex.1 A 25 KVA , 3300/ 230V , 50 Hz , 1 phase transformer draws no load current of 15 A when excited on load voltage side and consumes 350 watts. Calculate two components of current . Aktu – 2003-04

$I_0 = 15A$, $P = 350$ watt

$P = V_1 I_0 \cos\phi_0$, $\cos\phi_0 = \frac{P}{V_1 I_0}$

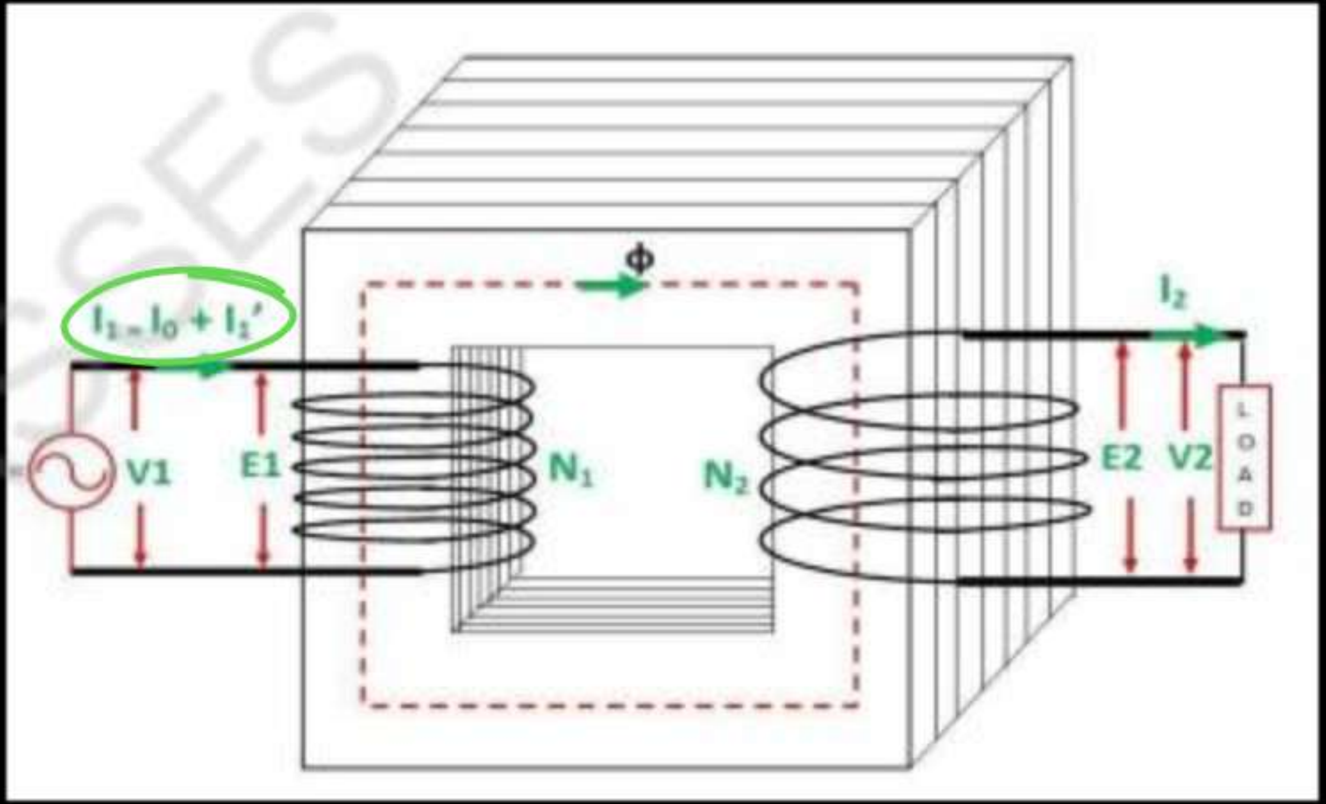
$\cos\phi_0 = \frac{350}{230 \times 15} = 0.1014$

$I_w = I_0 \cos\phi_0 = 15 \times 0.1014 =$

$I_m = I_0 \sin\phi_0 = 15 \times 0.9948 =$

Transformer on Load

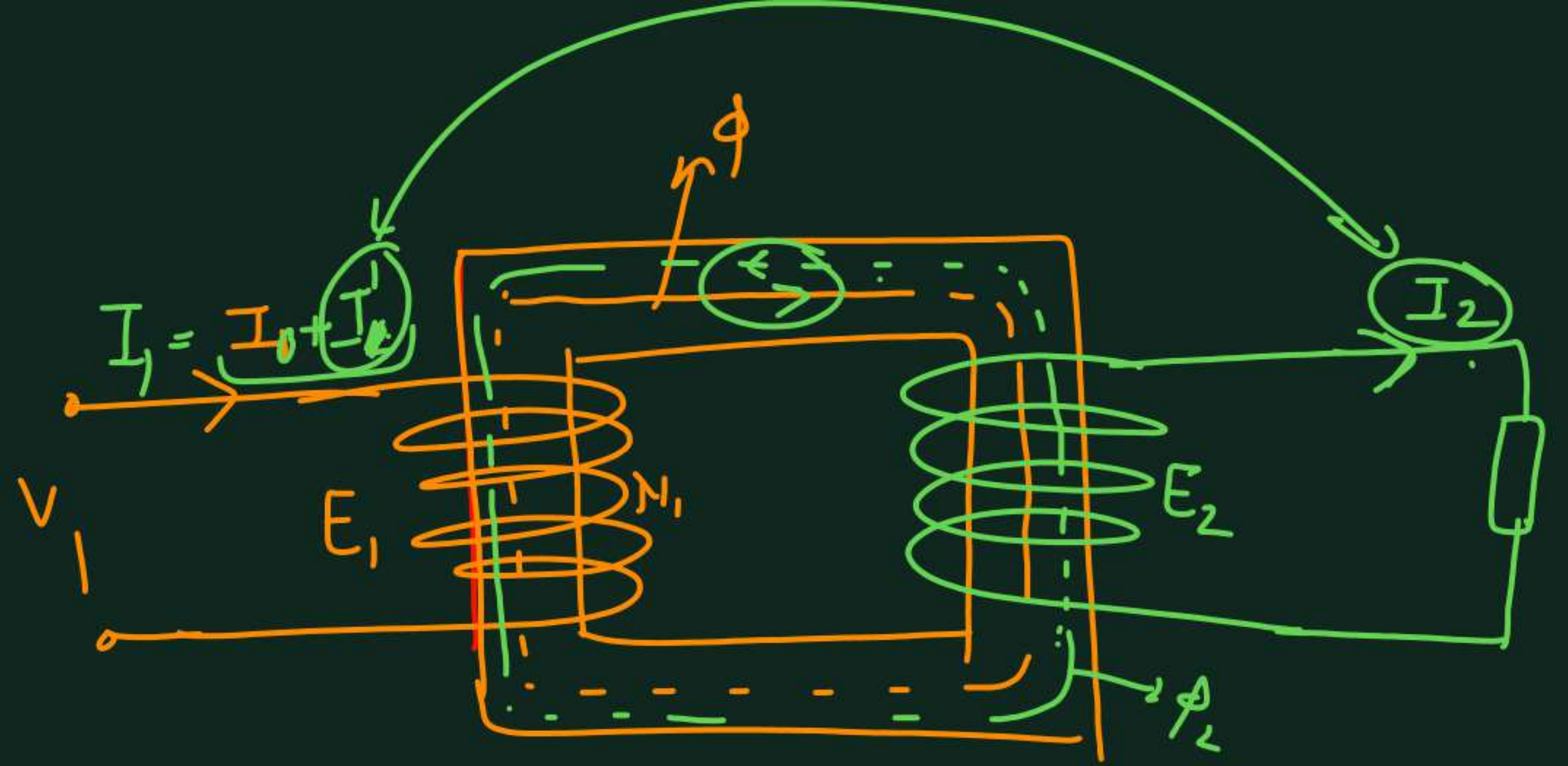
- When the secondary is kept open, it draws the no-load current from the main supply. The no-load current induces the mmf $N_0 I_0$ and this force set up the flux Φ in the



- When the load is connected to the secondary of the transformer, I_2 current flows through their secondary winding. The secondary current induces the mmf $N_2 I_2$ on the secondary winding of the transformer. This force set up the flux ϕ_2 in the transformer core. The flux ϕ_2 opposes the flux ϕ, according to **Lenz's law**.

- flux ϕ_2 opposes the flux ϕ, the resultant flux of the transformer decreases and this flux reduces the induced EMF E_1. Thus, the strength of V_1 is more than E_1 and an additional primary current I'_1 drawn from the mains.
- The additional current is used for restoring the original value of the flux in the core of the transformer so that $V_1 = E_1$. The primary current *I'_1 is in phase opposition with the secondary current I_2.*

- The additional current I'_1 induces the mmf $N_1 I'_1$. And this force set up the flux ϕ'_1. The direction of the flux is the same as that of the ϕ and it cancels the flux ϕ_2 which induces because of the MMF $N_2 I_2$



I1 = I0 + I2'
ϕ
I2
V1
E1
N1
E2
ϕ2

Transformer on Load

- Now, $N1I1' = N2I2$

  Therefore,

$$I_1' = \left(\frac{N_2}{N_1}\right) I_2 = KI_2$$

- The phase difference between V1 and I1 gives the power factor angle φ1 of the primary side of the transformer.

- The power factor of the secondary side depends upon the type of load connected to the transformer.

- The total primary current I1 is the vector sum of the currents I0 and I1'.

$$\overline{I_1} = \overline{I_0} + \overline{I_1'}$$

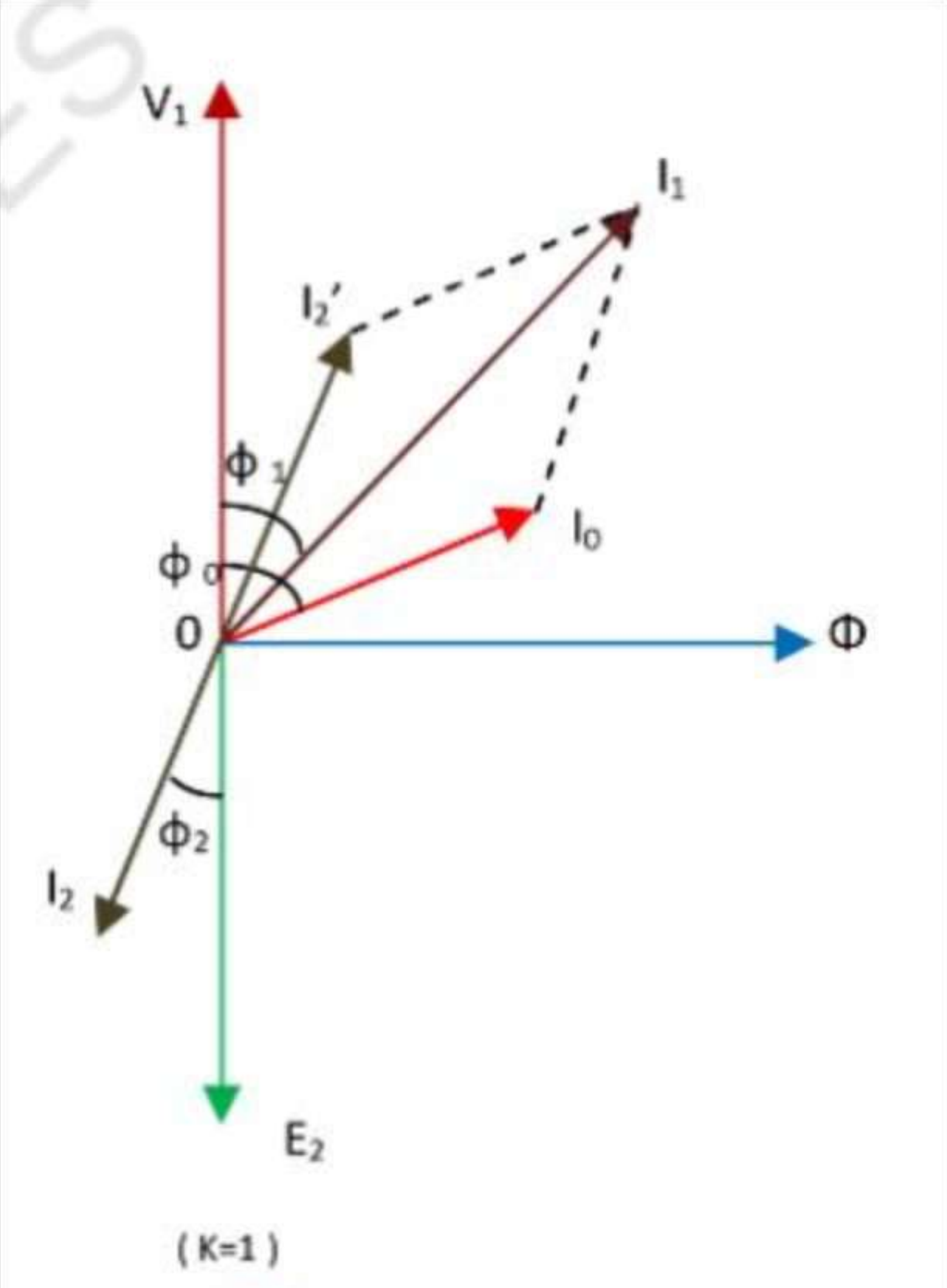
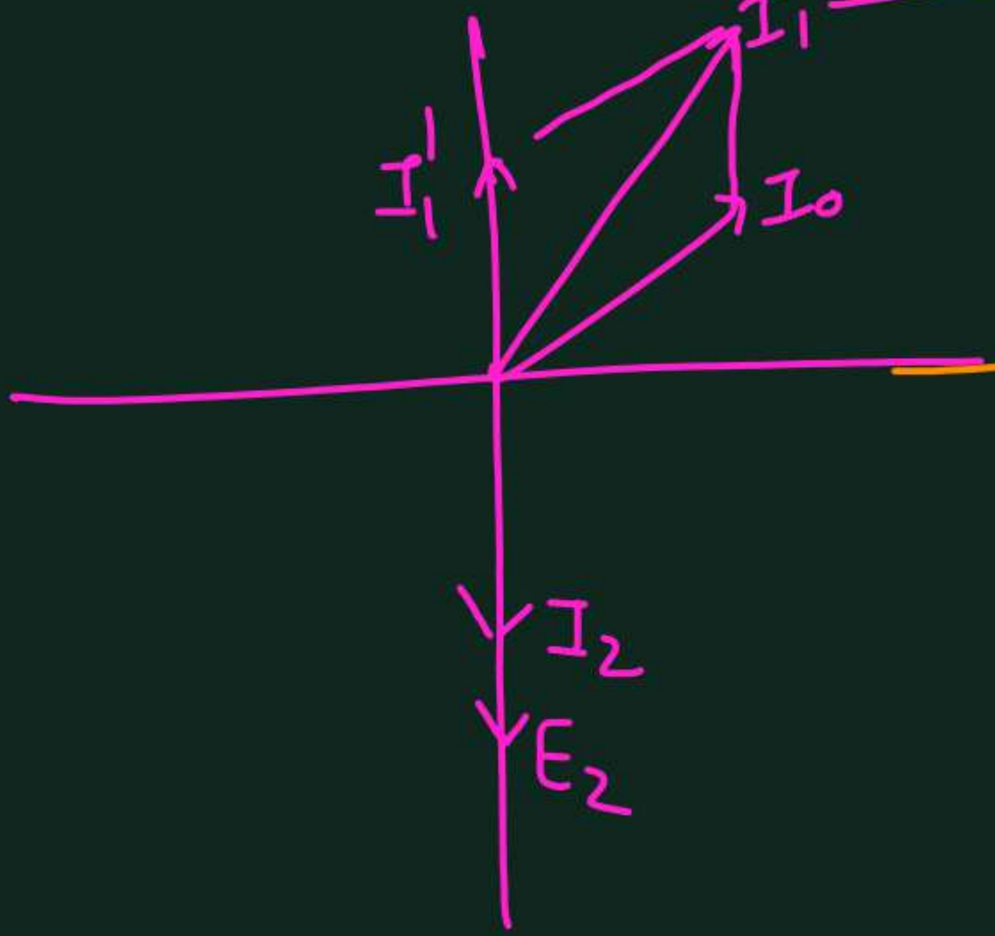


Fig-2

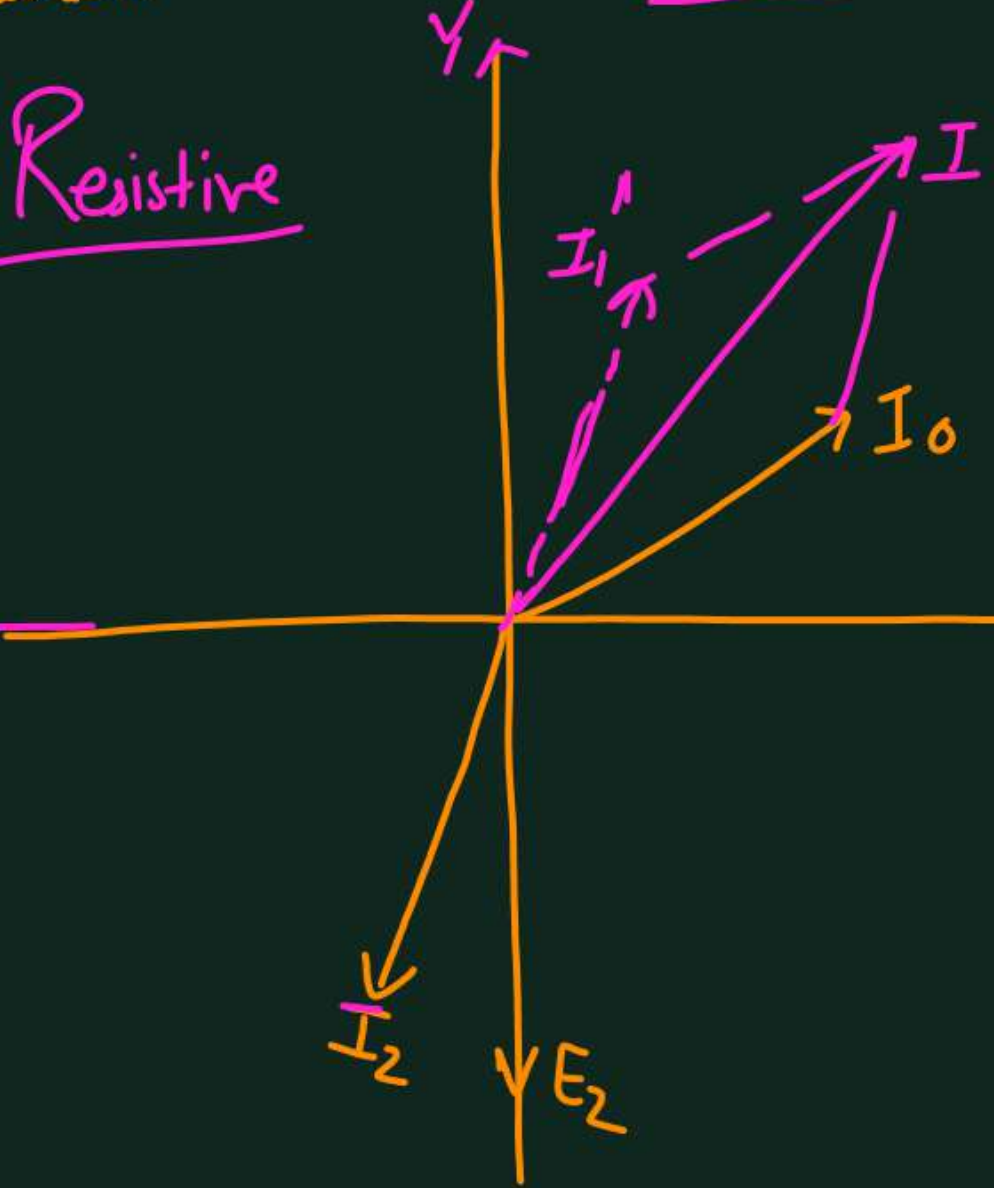
Load inductive

$I_1 = I_0 + I_1'$

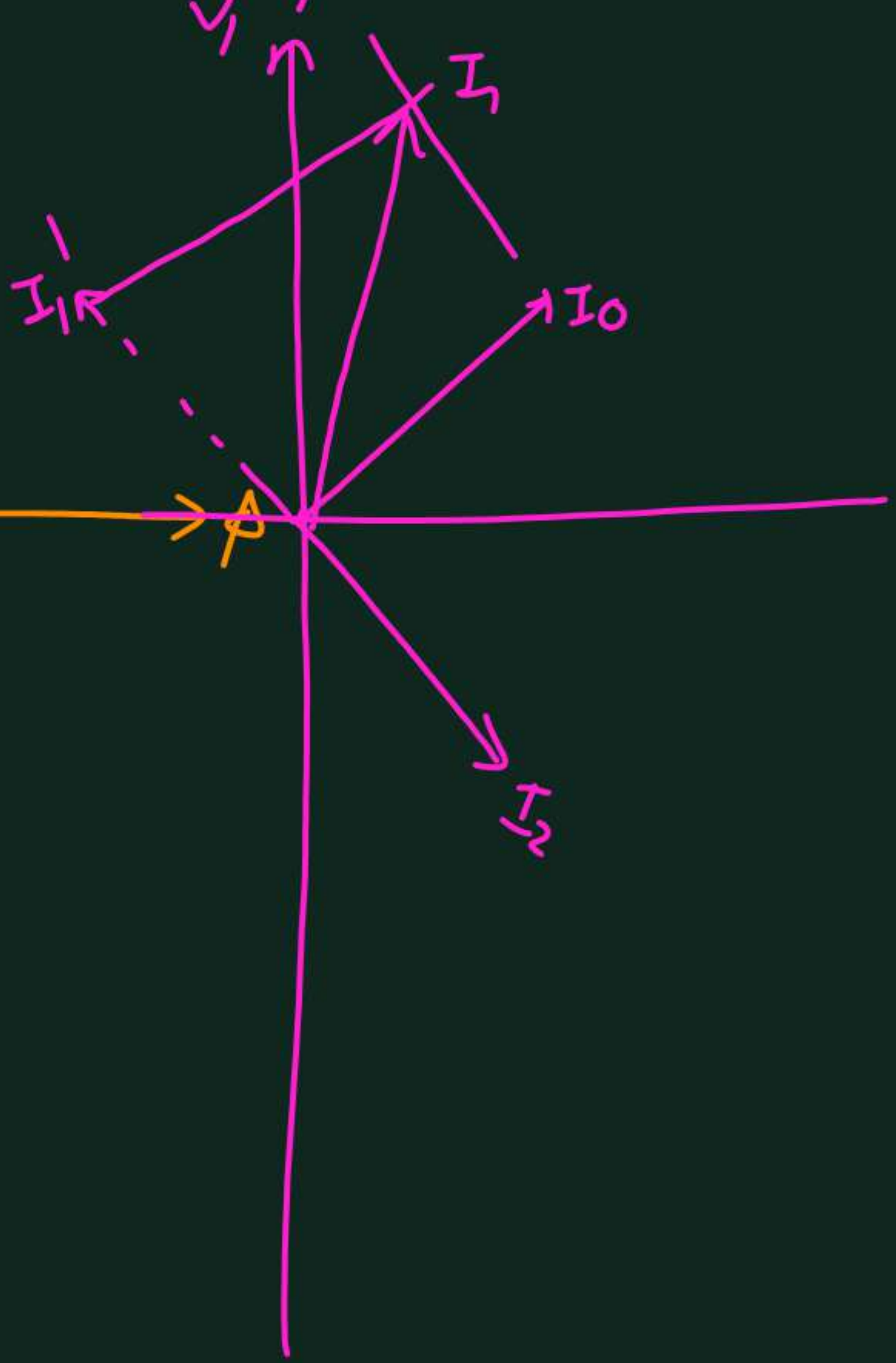
Resistive



Inductive



Capacitive

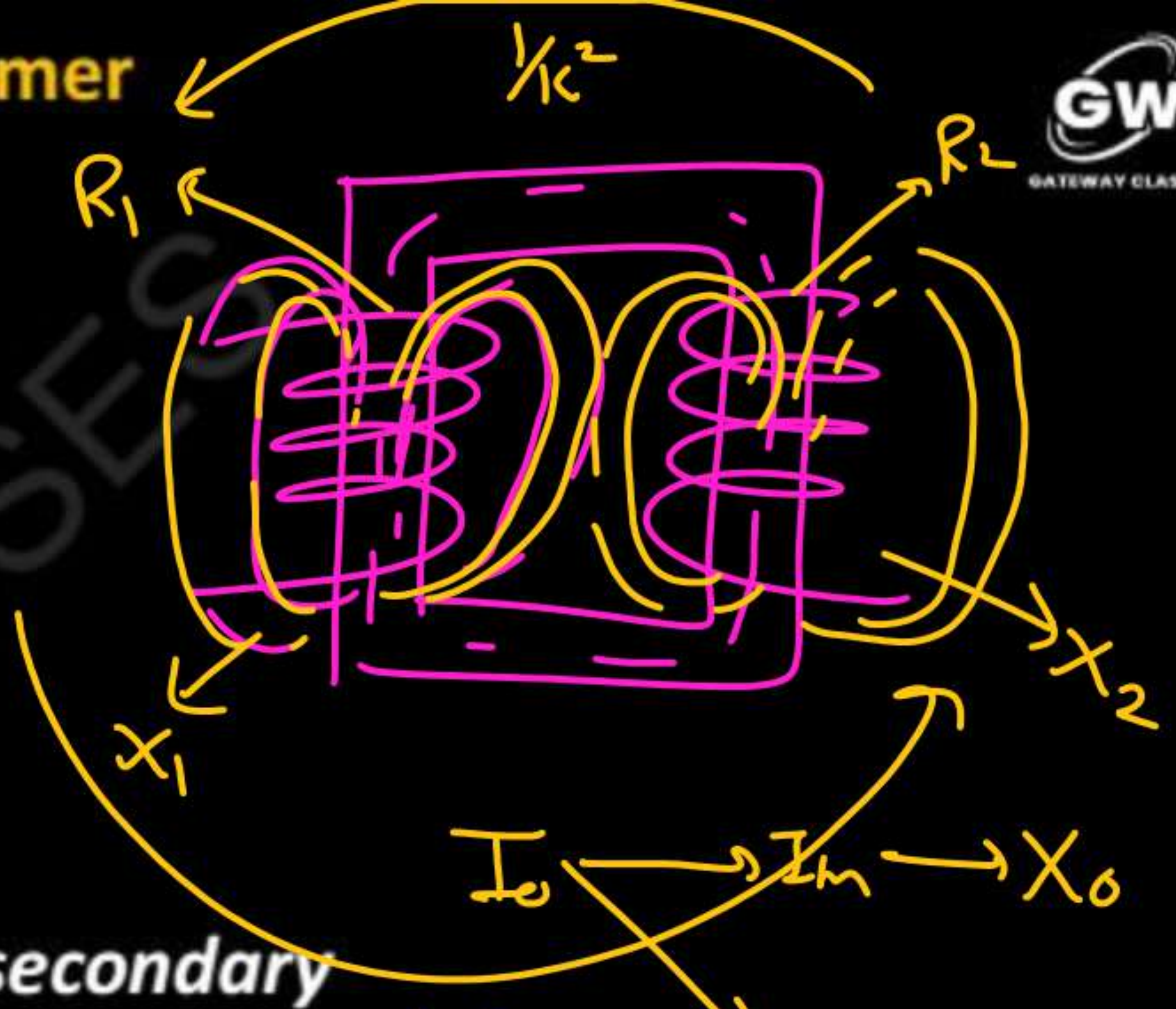


Equivalent circuit of Transformer

Concept of Leakage reactance:-

Primary
$R_1 \rightarrow$ Resi
$X_1 \rightarrow$ leakage React.

Secondary
R_2 = Resistance
X_2 = leakage Reac.

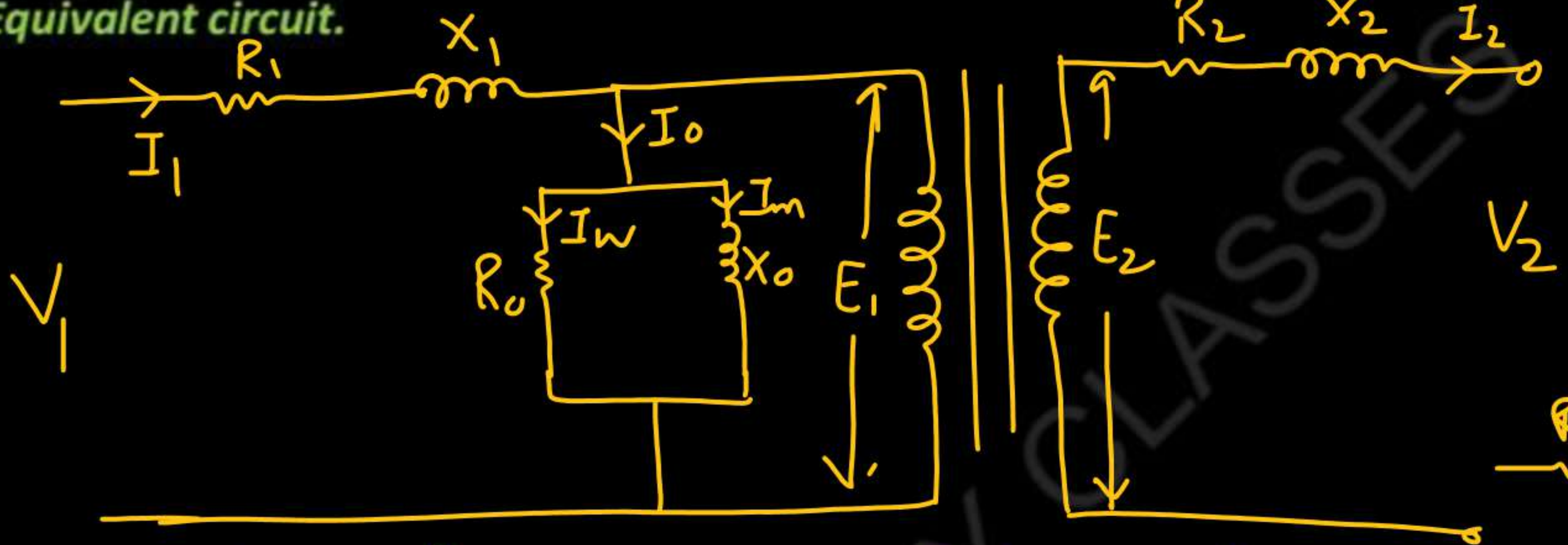


Concept of equivalent resistance:- referred to primary and secondary

$$\text{Total loss} = I_1^2 R_1 + I_2^2 R_2$$
$$= I_1^2\left(R_1 + \left(\frac{I_2}{I_1}\right)^2 R_2\right) = I_1^2\left(R_1 + \frac{R_2}{K^2}\right)$$
$$= I_1^2 R_1 + I_1^2 \frac{R_2}{K^2}$$

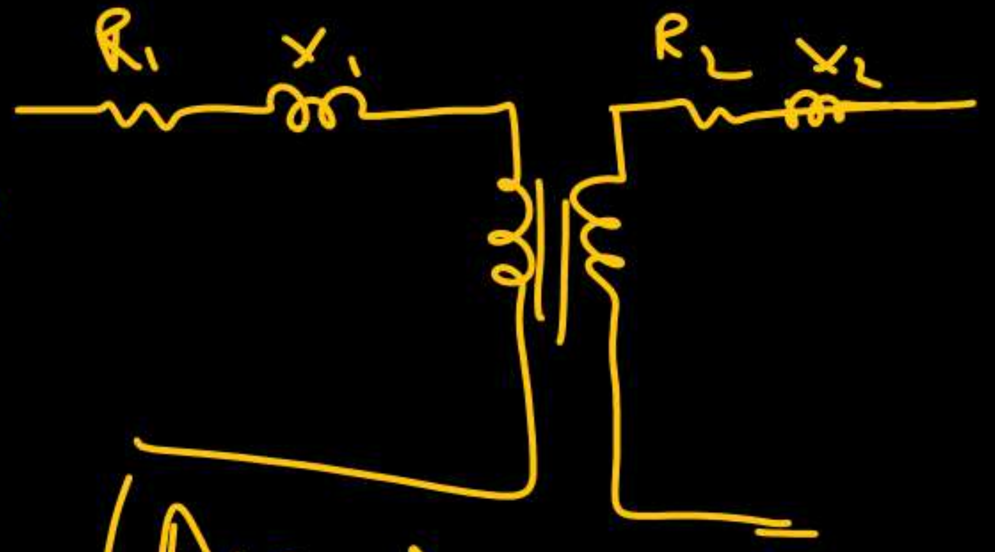
Equivalent circuit of Transformer

Exact Equivalent circuit.



R_1, X_1 = Primary resistance & leakage Reactance

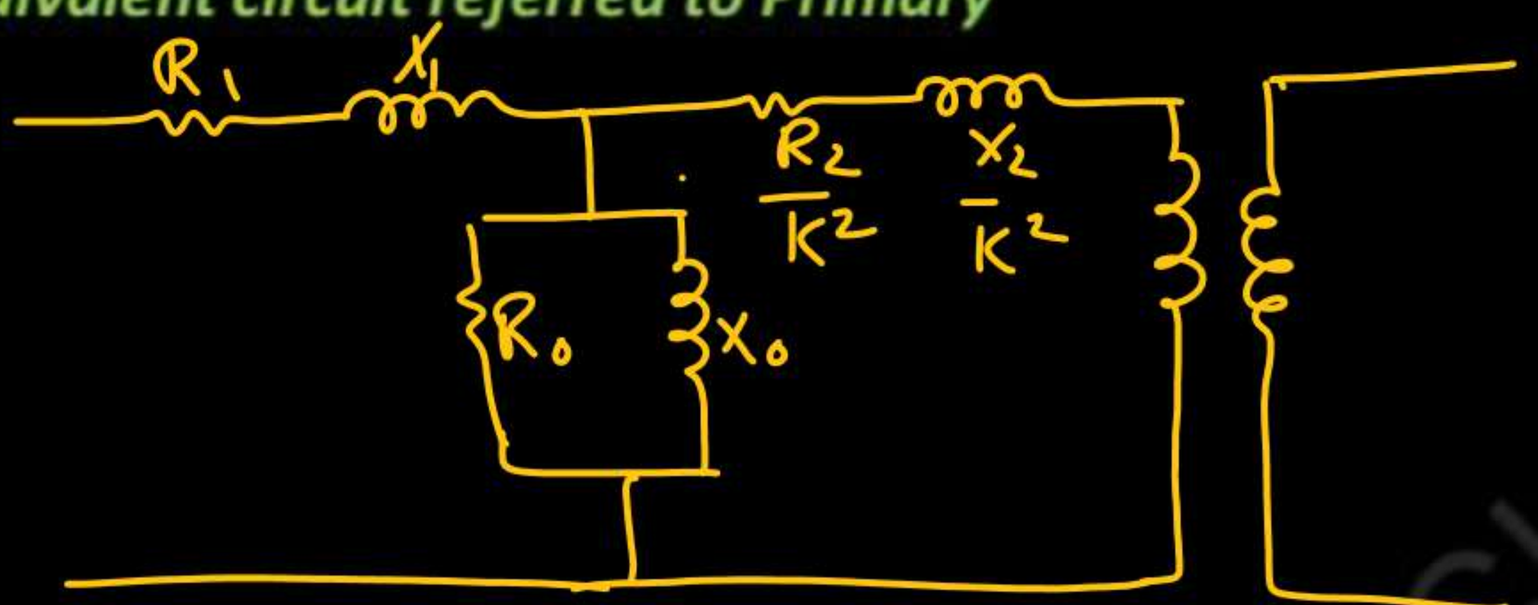
R_2, X_2 = Secondary " " " "

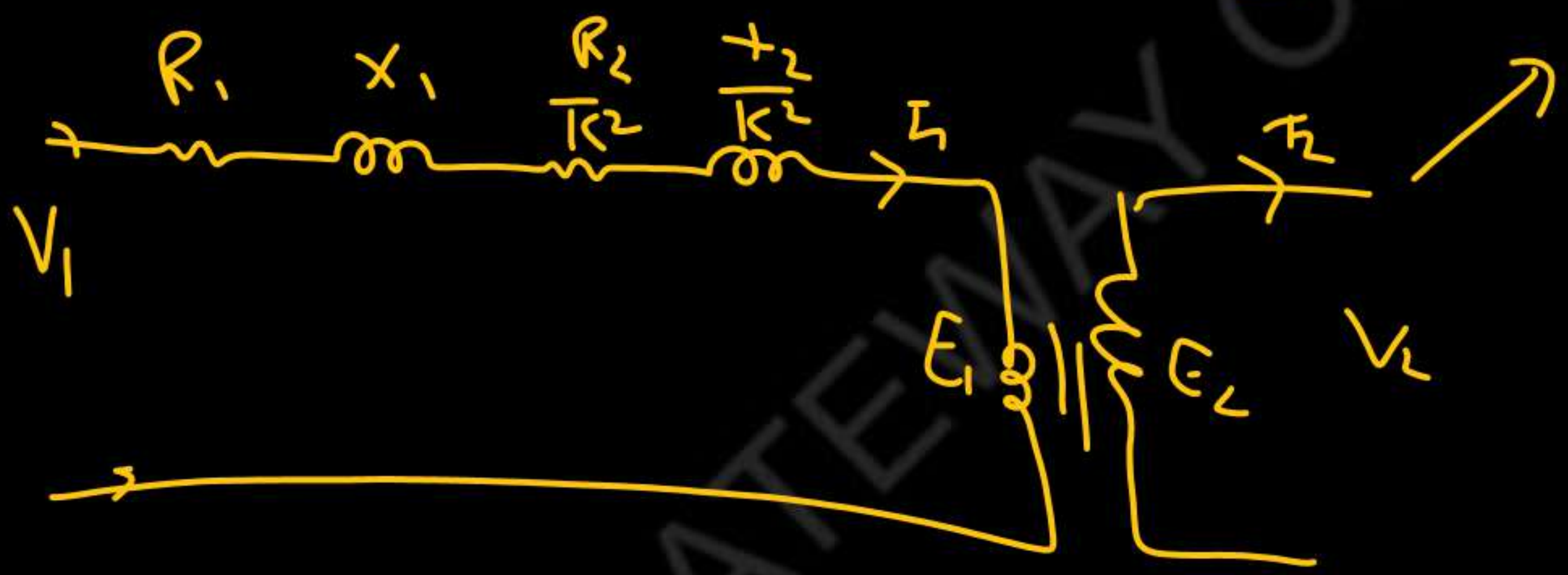


(Approximate Equivalent Ckt)

Equivalent circuit of Transformer

Exact Equivalent circuit referred to Primary





$$R_{01} = R_1 + \frac{R_2}{K^2}$$

$$X_{01} = X_1 + \frac{X_2}{K^2}$$

$$Z_{01} = \sqrt{R_{01}^2 + X_{01}^2}$$

$$Z_{01} = R_{01} + jX_{01}$$

Equivalent circuit of Transformer

Exact Equivalent circuit referred to Secondary

$$R_{02} = R_2 + R_1K^2$$

$$X_{02} = X_2 + X_1K^2$$

$$Z_{02} = R_{02} + jX_{02}$$

Primary Secondary

Total loss = Cu loss + Cu loss

Ref to Primary

$$= I_1^2 R_{01}$$

Ref. to Secondary

$$\text{Total} = I_2^2 R_{02}$$

Numerical

Ex-1 A 20kVA, 2000V/200V, single-phase, 50 Hz transformer has a primary resistance of 1.5 Ω and reactance of 2 Ω. The secondary resistance and reactance are 0.015 Ω and 0.02 Ω respectively. The no load current of transformer is 1A at 0.2 power factor. Determine: (i) Equivalent resistance, reactance and impedance referred to primary & Secondary (ii) Supply current (iii) Total copper loss Draw approximate equivalent circuit 2021-22

$R_1 = 1.5, X_1 = 2\,\Omega$

$R_2 = 0.015, X_2 = 0.02\,\Omega$

$K = \frac{200}{2000} = \frac{1}{10}$

Ref. to Primary

$R_{01} = R_1 + \frac{R_2}{K^2} = 1.5 + \frac{.015}{\frac{1}{100}}$

$= 1.5 + 1.5 = 3\,\Omega$

$X_{02} = X_1 + \frac{X_2}{K^2} = 2 + \frac{.02}{\frac{1}{100}} = 4\,\Omega$

$\boxed{Z_{01} = 3 + 4j\,\Omega}$

Ref. to Secondary

$R_{02} = R_2 + R_1 K^2$

$= 0.015 + 1.5 \times \frac{1}{100} = 0.030\,\Omega$

$X_{02} = X_2 + X_1 K^2$

$= .02 + 2 \times \frac{1}{100} = 0.04\,\Omega$

$Z_{02} = 0.03 + 0.02j$ Ans

$P = V_1 I_1$

$I_1 = \frac{20 \times 10^3}{2000} = 10$ amp

Total -

$= I_1^2 R_{01}$

$= 10^2 \times 3$

$= 300$ watt Ans

Img

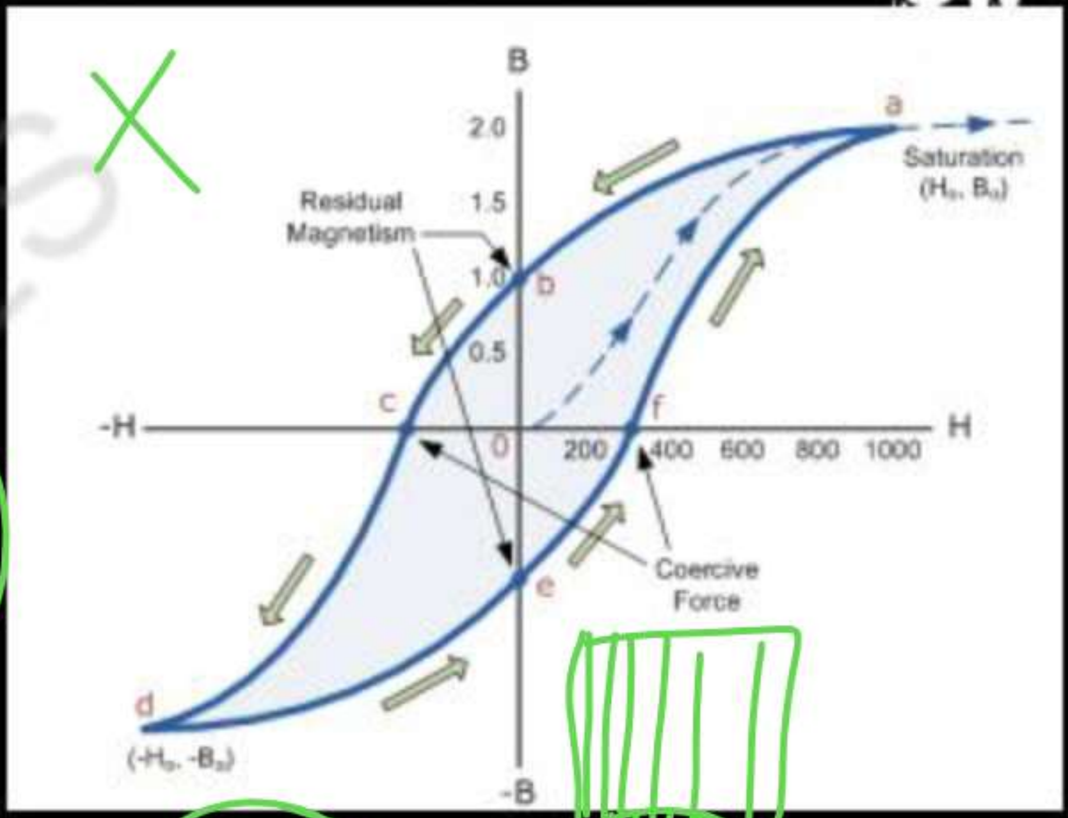
Losses in a Transformer

- **Core Loss/ Iron Loss/ Fixed Loss/ Constant Loss**

1. **Hysteresis Loss:-** When a magnetic material is subjected to cycle of magnetization , a power loss occurs due to molecular friction in the material Therefore, energy is required in the material to overcome this opposition. This loss being in the form of heat and is termed as *hysteresis loss.*

$$\text{Area of hysteresis loop} \propto B_{max}^{1.6}$$

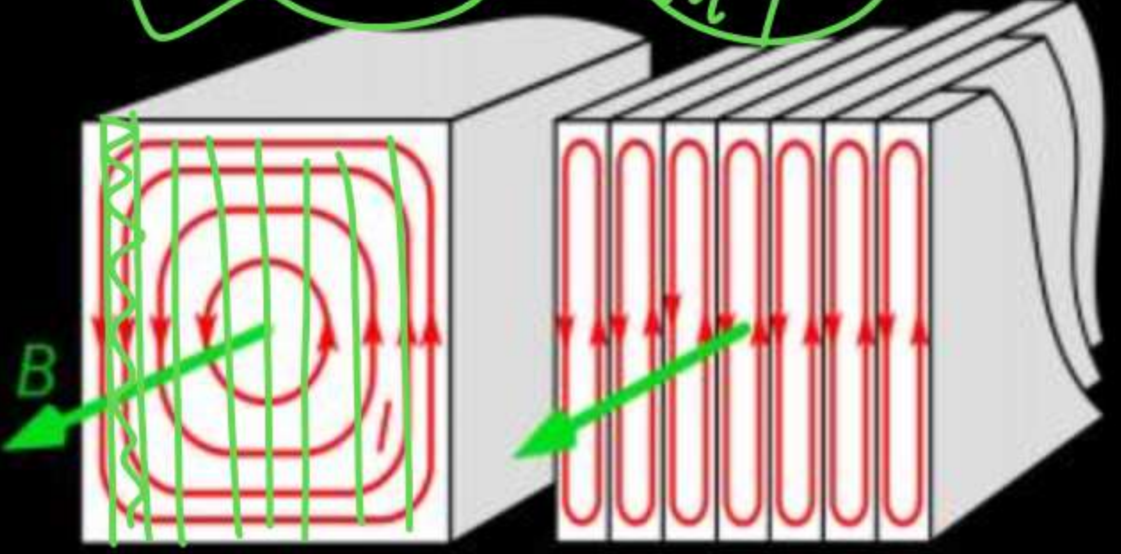
$$\textit{Hysteresis power loss, } P_h = \eta B_{max}^{1.6} f\, V \text{ Watts}$$



2. **Eddy Current Loss:-** When a magnetic material is subjected to a changing magnetic field, a voltage is induced in the material according to Faraday's law of electromagnetic induction. Since the material is conducting, the induced voltage circulates currents within the body of the magnetic material. These circulating currents are known as *eddy currents*. These eddy currents causes I^2R loss in the material, known as *eddy current loss.*

$$\textit{Eddy current power loss, } P_e = K_e B^2_{max} f^2 t^2 V \text{ Watts}$$

Where K_e = Eddy current coefficient, B_{max}= Maximum flux density, f = frequency of magnetization or flux, t = thickness of lamination, and V = Volume of magnetic material.



Methods of reducing Losses in a Transformer

Copper Loss/ Variable Loss/ I^2R Loss

- **Copper Loss:-** The losses are occurs due the resistance of primary and secondary winding. These losses are depends upon the magnitude of current in winding.

$$P_{cu} \propto I^2$$

$$P_{cu} = I^2 R$$

- *Thus for a Transformer Total Losses = Iron Loss + Copper Loss =* $P_i + P_{cu}$

Methods of reducing Losses in a Transformer

Iron Loss:- (i) Choice of Material for Iron Core (steel of high silicon content)

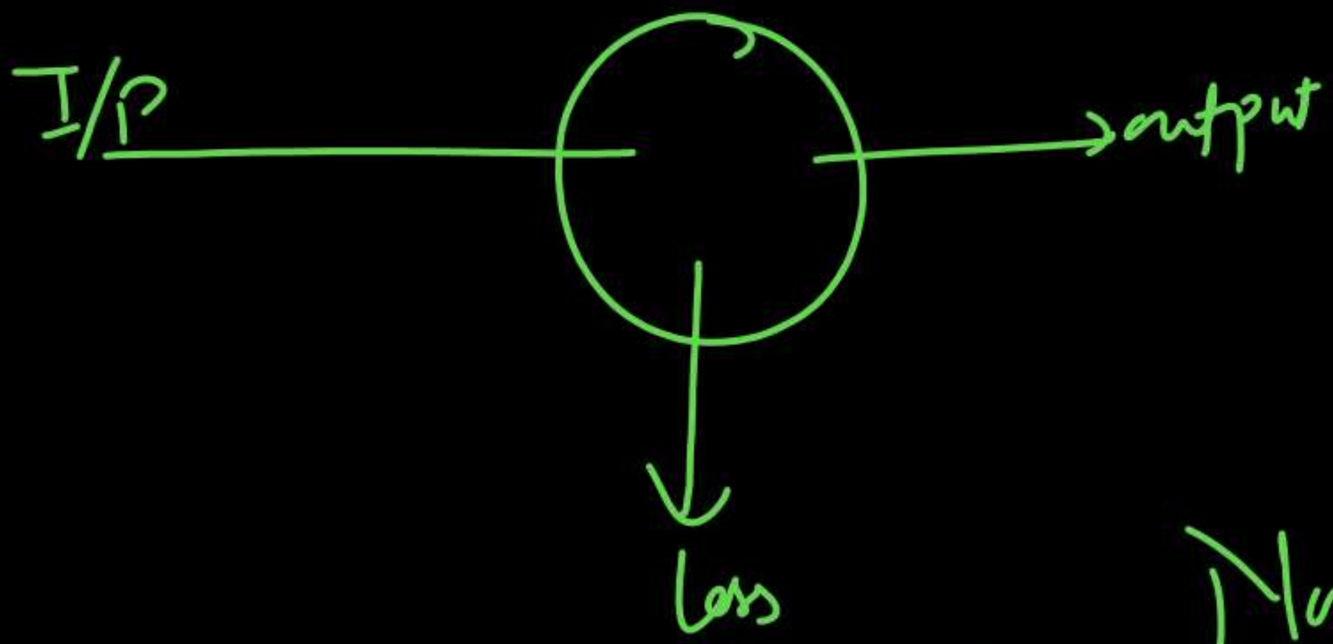
(ii) Use of Thin Laminated Core

Copper Loss/ Variable Loss/ I^2R Loss

(i) Reduce resistance of winding (use of thick wire)

Efficiency of Transformer

- **Efficiency of Transformer:-**



$I/p - \text{losses} = \text{output}$

$I/p = \underline{\text{output} + \text{losses}}$

$$\eta = \frac{\text{output}}{\text{Input}} = \frac{\text{output}}{\text{output} + \text{losses}} = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi + P_i + P_{cu}}$$

$P_{cu} \rightarrow I^2R$

Now Loading fraction $= x = 0.5$

0.25

Loading Current

$$\boxed{\eta = \frac{x V_2 I_2 \cos\phi}{x V_2 I_2 \cos\phi_2 + P_i + x^2 P_{cu}}}$$

Efficiency of Transformer

Condition of Maximum Efficiency of a Transformer:-

$$\eta = \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + P_i + I_2^2 R}$$

$$\frac{d\eta}{dI_2} = 0$$

$$\eta = \frac{\left[(V_2 I_2 \cos\phi + P_i + I_2^2 R)\, V_2 \cos\phi\right] - (V_2 I_2 \cos\phi)(V_2 \cos\phi + 0 + 2 I_2 \cdot R)}{(V_2 I_2 \cos\phi + P_i + I_2^2 R)^2} = 0$$

$$= (\cancel{V_2 I_2 \cos\phi} + P_i + I_2^2 R) - \cancel{V_2 I_2 \cos\phi} - 2 I_2^2 R = 0$$

$$P_i - I_2^2 R$$

$$P_i = I_2^2 R \Rightarrow \boxed{P_i = P_{cu}}$$

At any load

$$\boxed{P_i = x^2 P_{cu}}$$

Efficiency of Transformer

Load Current at Maximum Efficiency :-

$$I_2^2 R_{02} = P_i$$

$$I_2^2 = \frac{P_i}{R_{02}} \Rightarrow I_2 = \sqrt{\frac{P_i}{R_{02}}}$$

$$\frac{I_2}{I_{f.L}} = \frac{1}{I_{f.L}}\sqrt{\frac{P_i}{R_{02}}} = \sqrt{\frac{P_i}{I_{f.L}^2 R_{02}}} \Rightarrow \sqrt{\frac{P_i}{P_{cu.f.L}}}$$

$$\boxed{I_2 = I_{f.L} \times \sqrt{\frac{P_i}{P_{cu}}}}$$

KVA at Maximum Efficiency:-

$$KVA = V_2 I_2 = \underbrace{V_2 \cdot I_{f.L}}\sqrt{\frac{P_i}{P_{cu}}} \Rightarrow (KVA)_{f.L}\sqrt{\frac{P_i}{P_{cu}}}$$

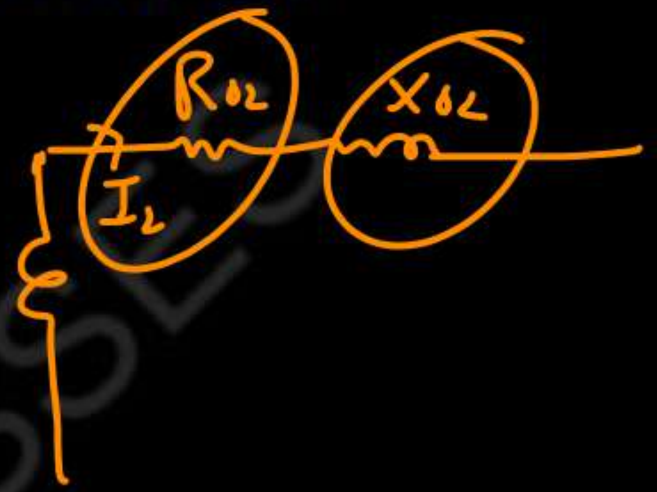
Voltage Regulation of a Transformer

$$\% V.R = \frac{E_2 - V_2}{V_2}$$

$$= \frac{I_2 R_{02} \cos\phi \pm I_2 X_{02} \sin\phi}{V_2}$$

lagging

leading.



Numericals

$P_i = P_{cu}$

$= 2P_i$

$V_2 I_2$

Ex-1 A $\boxed{40 \text{ KVA}}$ transformer has iron loss of 450W and full load copper loss of 850W. if the power factor of the load is 0.8 lagging, calculate: (i) Full load efficiency (ii) The load at which the maximum efficiency occurs and (iii) The maximum efficiency. 2021-22

$P_i = 450\,W, \quad P_{cu} = 850\,W$

$\cos\phi = 0.8$

$$\eta_{f.l.} = \frac{40\times10^3\times0.8}{(40\times10^3\times0.8)+(450+850)}$$

$= 0.96$

$$\boxed{\% \eta_{f.L} = 96\%}$$

$$(KVA)_{max.} = KVA_{f.L}\sqrt{\frac{P_i}{P_{cu}}} = 40\sqrt{\frac{450}{850}} = 2910\ VA.$$

$$\eta_{max} = \frac{2910\times0.8}{(2910\times0.8)+2P_i} = \frac{2328}{2328+(2\times450)} = 96.27\%$$

Numericals

GW GATEWAY CLASSES

Ex-2 A 25kVA, 2000/200V transformer has full load copper and iron losses of 1.8kW and 1.5kW respectively. Calculate efficiency at half the rated kVA and at unity power factor, the efficiency at full load and at 0.8 pf lagging and maximum efficiency. 2020-21

$P_i = 1.5\,kW$, $P_{cu} = 1.8\,kW$

$x = 0.5$

$$\eta_{1/2} = \frac{(0.5)\times(25\times10^3)\times 1}{(0.5\times25\times10^3\times1)+\left(1500+\frac{1800}{4}\right)}$$

x^2

$$\boxed{\eta_{1/2} = 86.5\%}$$

$$\eta_{fl} = \frac{25\times10^3\times0.8}{(25\times10^3\times0.8)+(1500+1800)}$$

$$= 85.83\%$$

$$kVA_{max} = 25\times10^3\times\sqrt{\frac{1500}{1800}} = 22821.7\,VA$$

$$\eta_{max} = \frac{22821.7\times0.8}{22821.7\times0.8+(2\times1500)} = 85.88\%$$

Ans

Ex-3 A single phase 100KVA 6.6kv , 230V 50Hz transformer has 90% efficiency at 0.8 lagging power factor both at full load and also at half load. Determine iron and copper loss at full load for the transformer. 2019-20

$\eta_{F.L} = 90\% = 0.90$, $\cos\phi = 0.8$

$\eta_{H.L}$

at full load

$$0.9 = \frac{100\times10^3\times0.8}{100\times10^3\times0.8 + (P_i + P_{cu})} \Rightarrow P_i + P_{cu} = 8888.8 \quad (1)$$

At half load

$$0.9 = \frac{0.5\times100\times10^3\times0.8}{0.5\times100\times10^3\times0.8 + \left(P_i + \frac{P_{cu}}{4}\right)} \Rightarrow P_i + \frac{P_{cu}}{4} = 4444.4 \quad (2)$$

Solve

$P_i = 2.9\,kW$

$P_{cu} = 5.9\,kW$

Ans

Numericals

GW GATEWAY CLASSES

Ex-4 The maximum efficiency of a 100 KVA, 1100/440 V, 50 Hz transformer is 96%, This occurs at 75% of full load at 0.8 p.f. lagging. Find the efficiency of transformer at 3.4 FL at 0.6 p.f. leading. 2018-19

$\eta_{max} = .96$ at load $= (100\times10^3)\times0.75 = 75\,KVA$

$x = 0.75$

$$0.96 = \frac{75\times10^3\times0.8}{75\times10^3\times0.8 + 2P_i}$$

$$\boxed{P_i = 1250\,watt}$$

$P_i = x^2 P_{cu}$

$$P_{cu} = \frac{P_i}{x^2} = \frac{1250}{(0.75)^2} = 2222.2\,watt$$

$x = \frac{3}{4}$, $\cos\phi = 0.6$

$$\eta_{f.L} = \frac{\frac{3}{4}\times100\times10^3\times0.6}{\left(\frac{3}{4}\times100\times10^3\times0.6\right) + \left(1250 + \left(\frac{3}{4}\right)^2 2222.2\right)}$$

$\eta_{f.L} = 88.33\%$

Ans

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Thank You