Unit - III

3.4 Ideal Transformer, Losses and Efficiency

Dr.Santhosh.T.K.

World's Largest Transformer

- *SIEMENS's [transformer factory] in Nuremberg (Germany) to China*
- 1,100KV transformer for the world's largest HVDC project in China
- capacity of 587 MVA
- Transformer size: 37.5 x 12 x 14.4 (m)
- Weight ~ 900 tons


WORLD'S BIGGEST TRANSFORMER

Syllabus

UNIT – III **10 Periods**

Principles of Electro Magnetics and Electro-mechanics: Electricity and Magnetism - magnetic field and faraday's law - self and mutual inductance - Ampere's law - Magnetic circuit - Magnetic material and B-H Curve – Single phase transformer - principle of operation - EMF equation - voltage ratio - current ratio – KVA rating - Electromechanical energy conversion – Elementary generator and motors.

Ideal Transformers

- **Zero leakage flux:**

  -Fluxes produced by the primary and secondary currents are confined within the core

- **The windings have no resistance:**

  - Induced voltages equal applied voltages

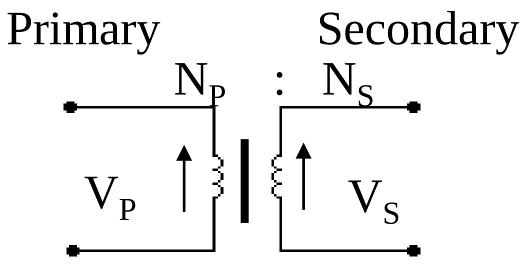
- **The core has infinite permeability**

  - Reluctance of the core is zero

  - Negligible current is required to establish magnetic flux

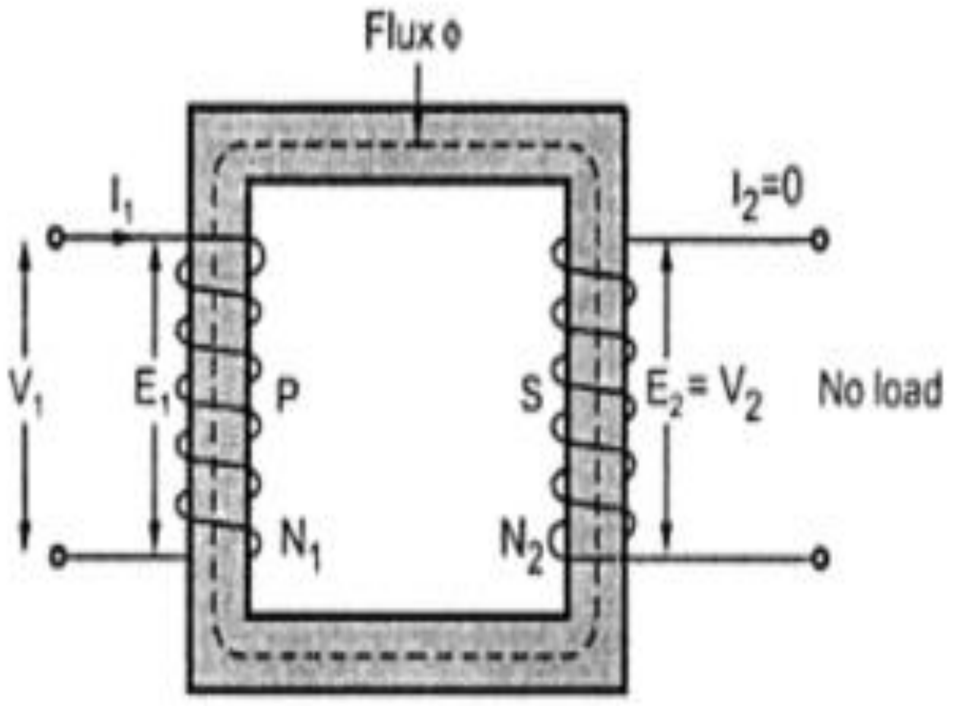
- **Loss-less magnetic core**

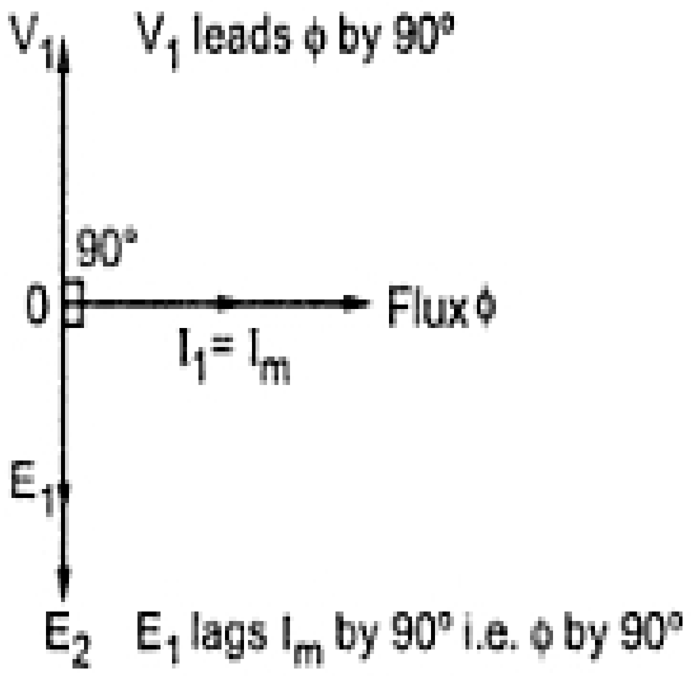
  - No hysteresis or eddy currents



Symbol for ideal transformer

Ideal transformer





V_1 – supply voltage ; I_1- noload input current ;

V_{2-} output voltgae; I_2- output current

I_m- magnetising current;

E_1-self induced emf ; E_2- mutually induced emf

Transformer Equations

Using Faraday's law, expressions for the primary and secondary voltages is as follows.

$$V_2 = N_2 \frac{d\Phi}{dt}. \qquad V_1 = N_1 \frac{d\Phi}{dt}.$$

Dividing the above equations we get,

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}.$$

Assuming that there is no power loss,

$$V_2 I_2 = V_1 I_1.$$

$$\frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1} = K.$$

K - transformation ratio

EMF Equation of a transformer

Let N_1= No. of primary turns

N_2= No. of secondary turns

ϕ_m= Maximum flux density in transformer core in Weber

=B_mA where B_m-> flux density in the transformer core

A -> cross sectional Area of the transformer

In an EMF equation, flux increases from its zero value to maximum value Φ_m in one quarter of cycle

Average rate of change of flux = $\Phi_m/(1/4f)=4f\,\Phi_m$ wb/sec ……(1)

The average value of emf induced / turn = $4f\,\Phi_m$ ……(2)

If flux Φ_m varies sinusoid ally, then R.M.S value of induced EMF is obtained by multiplying the average value with form factor.

EMF Equation of a transformer -contd

Form factor=R.M.S value/Average value $= \dfrac{Vm/\sqrt{2}}{2Vm/\pi}$ ……(3)

= 1.11 (for sine wave)

R.M.S value of EMF/turn=1.11*4fΦ_m volts ……(4)

Now,

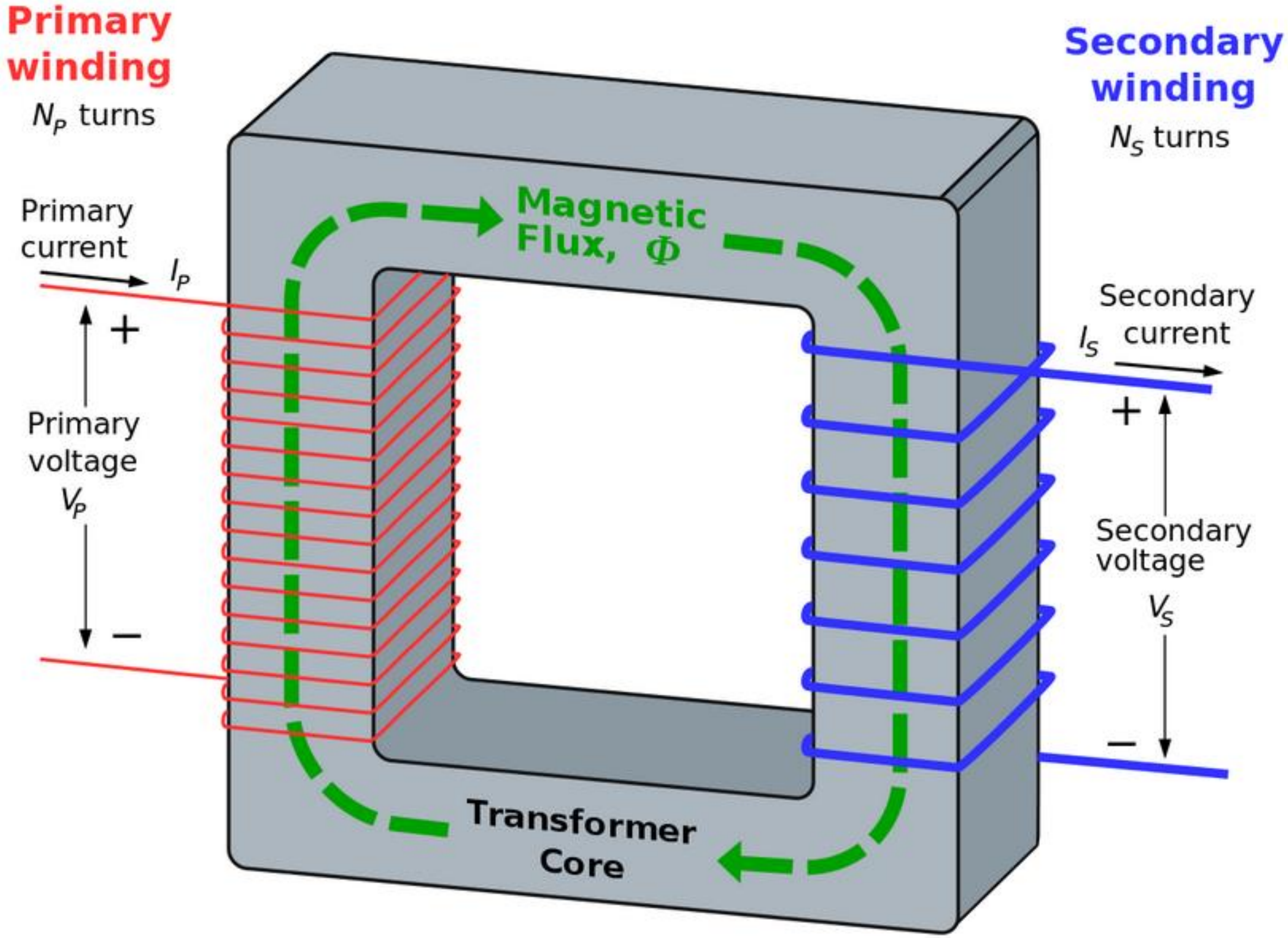
R.M.S value of the induced EMF in the whole primary winding = (induced EMF/turn)*No of primary turns.

$$E_1 = 4.44fN_1\Phi_m \quad \text{……(5)}$$

Illy,

$$E_2 = 4.44fN_2\Phi_m \quad \text{……(6)}$$

Transformer



EMF equation of transformer - contd

If i_p is sinusoidal, the flux produced also sinusoidal, i.e

$$\Phi = \Phi_m \sin 2\pi f t \qquad \ldots\ldots(7)$$

therefore $$v_1 = N_1 \frac{d\left(\Phi_m \sin 2\pi f t\right)}{dt}$$

$$v_1 = N_1 2\pi f \Phi_m \cos 2\pi f t = N_1 2\pi f \Phi_m \sin\left(2\pi f t + \pi/2\right) \qquad \ldots\ldots(8)$$

The peak value = $V_{pm} = N_1 2\pi f \Phi_m$ ……(9)

and v_1 is leading the flux by $\pi/2$.

The rms value $$V_1 = \frac{V_{1m}}{\sqrt{2}} = 0.707 \times N_1 2\pi f \Phi_m = 4.44 N_1 f \Phi_m \qquad \ldots\ldots(10)$$

Voltage regulation of Transformer

$$\text{Voltage regulation} = \frac{\text{no-load voltage} - \text{full-load voltage}}{\text{no-load voltage}}$$

recall $\dfrac{V_s}{V_p} = \dfrac{N_s}{N_p}$

Secondary voltage on no-load $V_2 = V_1\left(\dfrac{N_2}{N_1}\right)$

V_2 is a secondary terminal voltage on full load

Substitute we have

$$\text{Voltage regulation} = \frac{V_1\left(\frac{N_2}{N_1}\right) - V_2}{V_1\left(\frac{N_2}{N_1}\right)}$$

Transformer Efficiency

Transformer efficiency is defined as (applies to motors, generators and transformers):

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

$$\eta = \frac{P_{out}}{P_{out} + P_{loss}} \times 100\%$$

Types of losses incurred in a transformer:

- Copper I^2R losses
- Hysteresis losses
- Eddy current losses

Therefore, for a transformer, efficiency may be calculated using the following:

$$\eta = \frac{V_S I_S \cos\theta}{P_{Cu} + P_{core} + V_S I_S \cos\theta} x100\%$$

All day efficiency

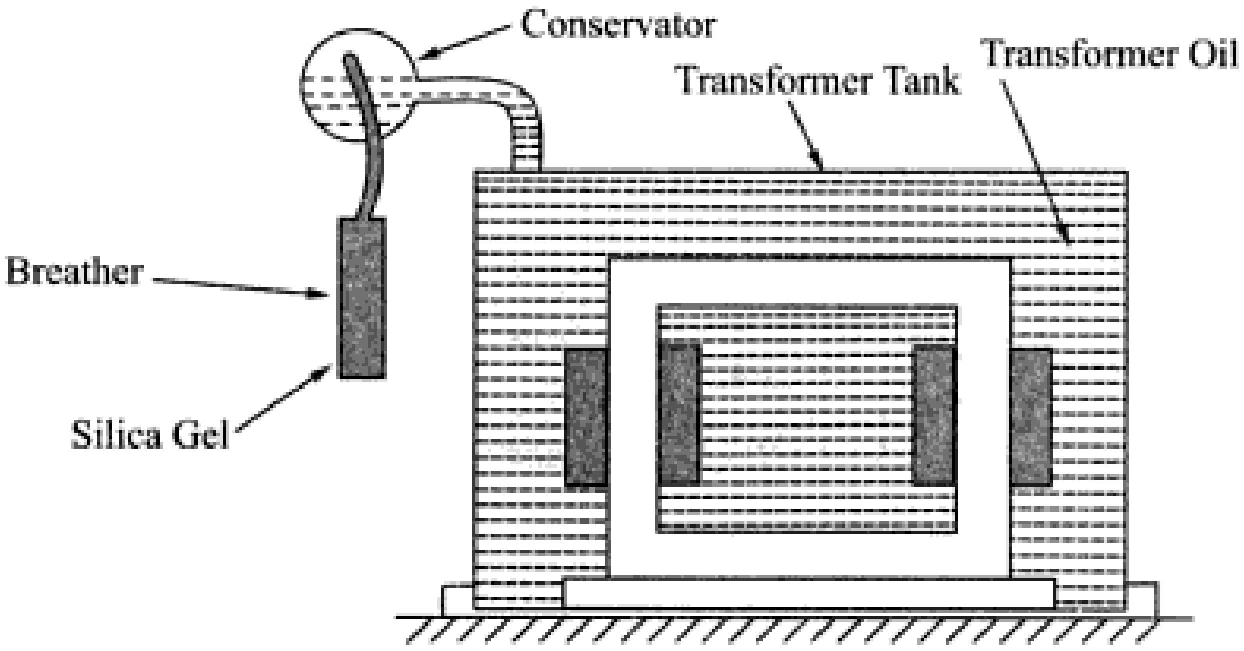
All day efficiency is defined as the ratio of total energy output of transformer to thetotal energy input in 24 hours.

$$\text{ordinary commercial efficiency} = \frac{\text{out put in watts}}{\text{input in watts}}$$

$$\eta_{all\,\text{day}} = \frac{\text{output in kWh}}{\text{Input in kWh}}(\,for\ 24\text{ hours})$$

•All day efficiency is always less than the commercial efficiency

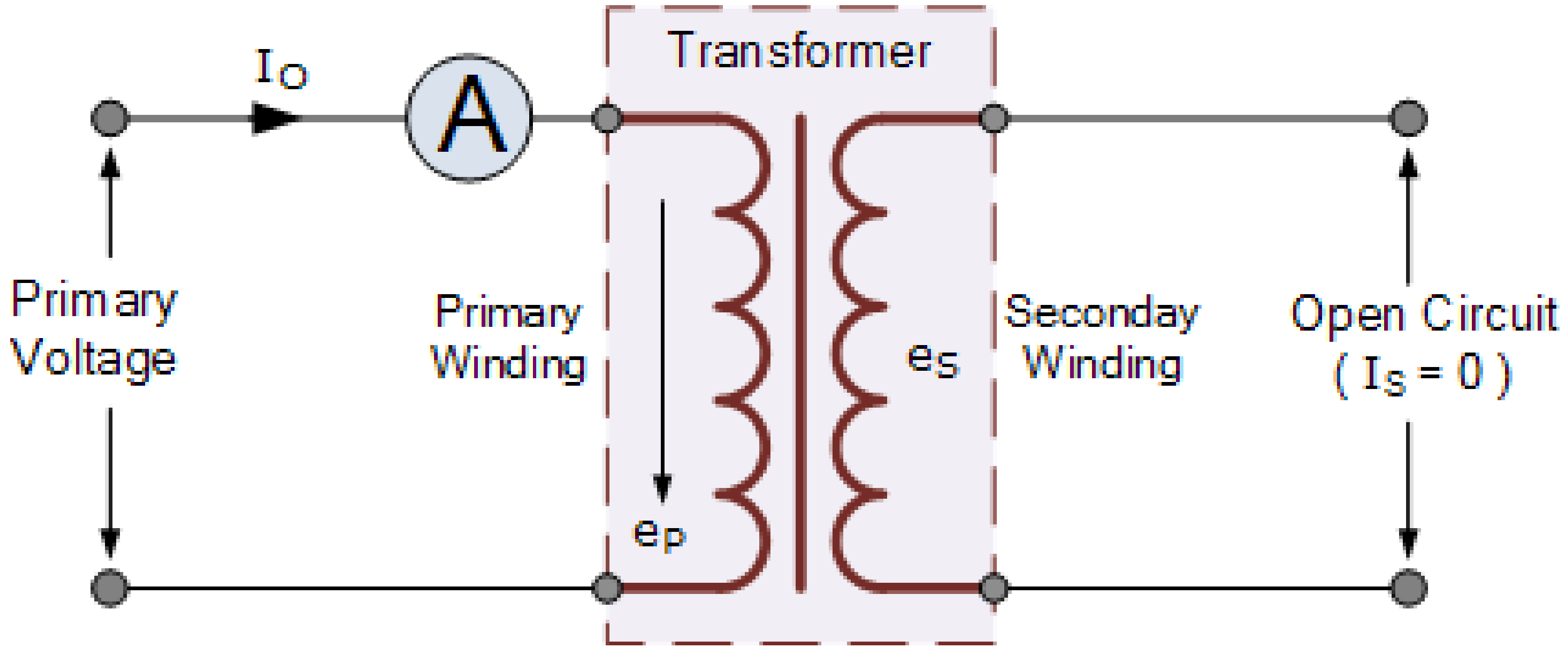
Transformer with conservator and breather



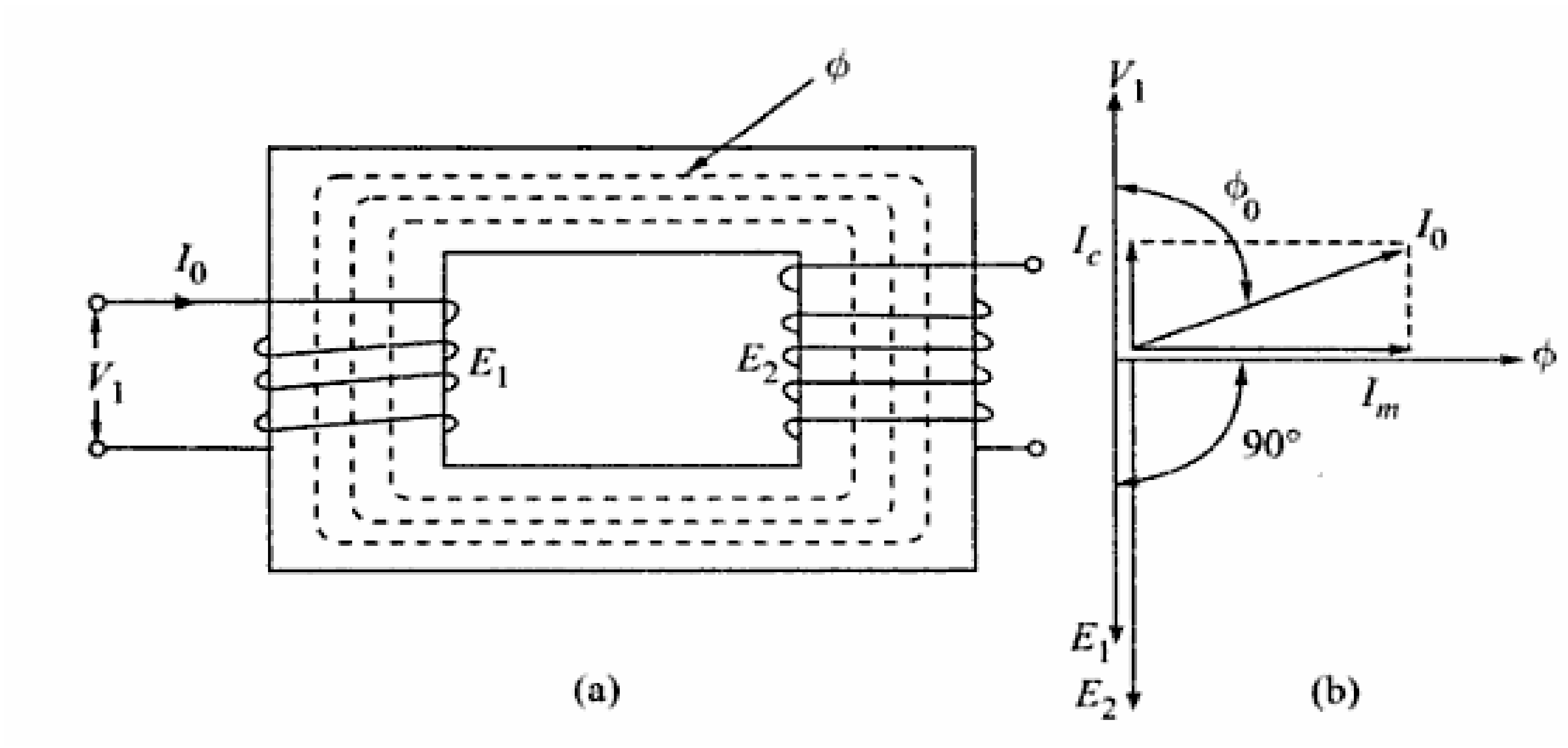
Parts of a transformer

- Conservator
  - Oil is stored in the conservator
  - It prevents the oil from moisture contact in air during the expansion and contraction.
- Breather
  - It is a device which contains silica gel crystals.
  - The gel absorbs the moisture in the atmosphere when the oil expands and contracts.
- Explosive Vent
  - It bursts when pressure inside the transformer becomes excessive and protects the transformer from damage.
- Transformer Tank filled with transformer Oil

Transformer-No load condition

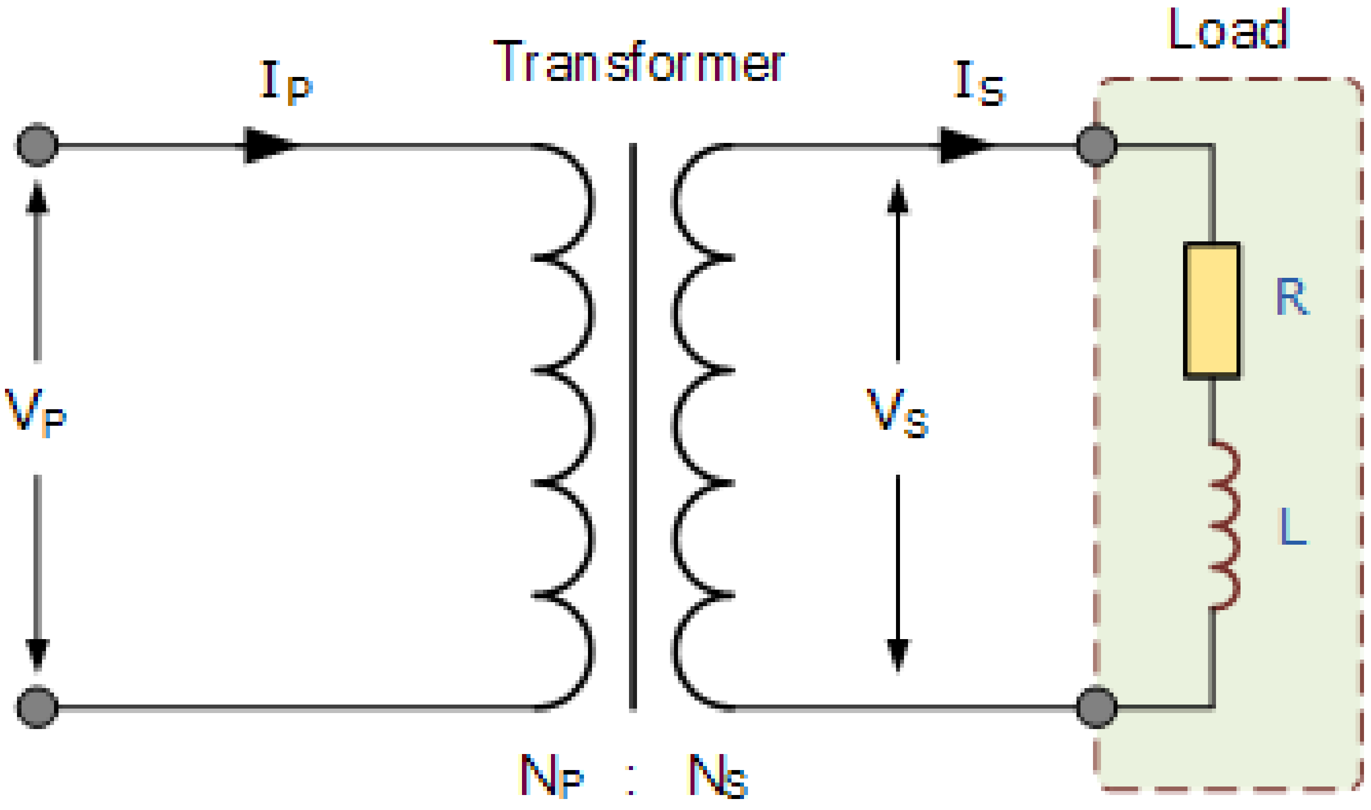


Phasor diagram: Transformer on No-load



(a) Transformer on no-load (b) Phasor diagram of a transformer on no-load

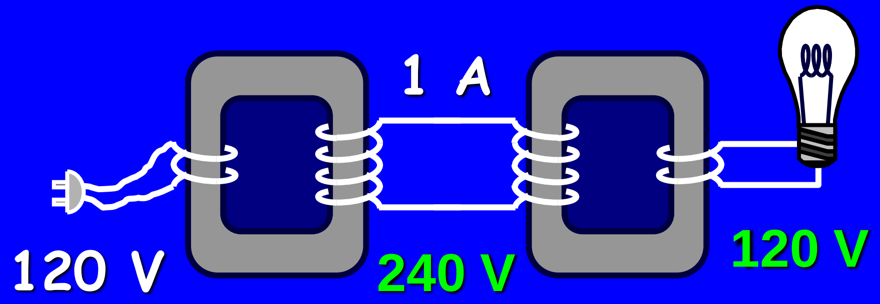
Transformer – On load condition



Transformers

Given that the intermediate current is 1 A, what is the current through the lightbulb?

1) 1/4 A
2) 1/2 A
3) 1 A
4) 2 A
5) 5 A



Transformers

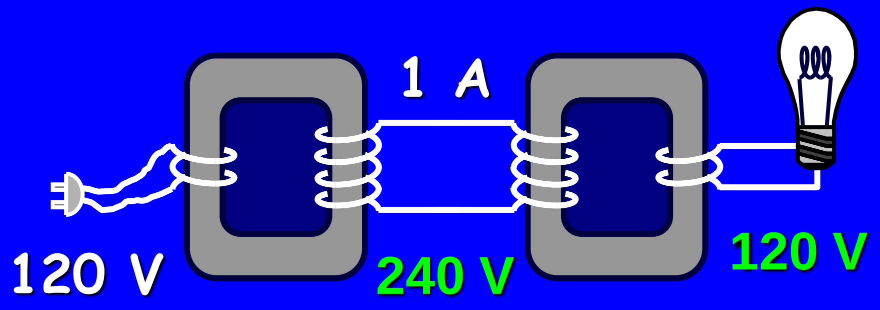
Given that the intermediate current is 1 A, what is the current through the lightbulb?

1) 1/4 A
2) 1/2 A
3) 1 A
4) 2 A
5) 5 A

Power in = Power out

240 V × 1 A = 120 V × ???

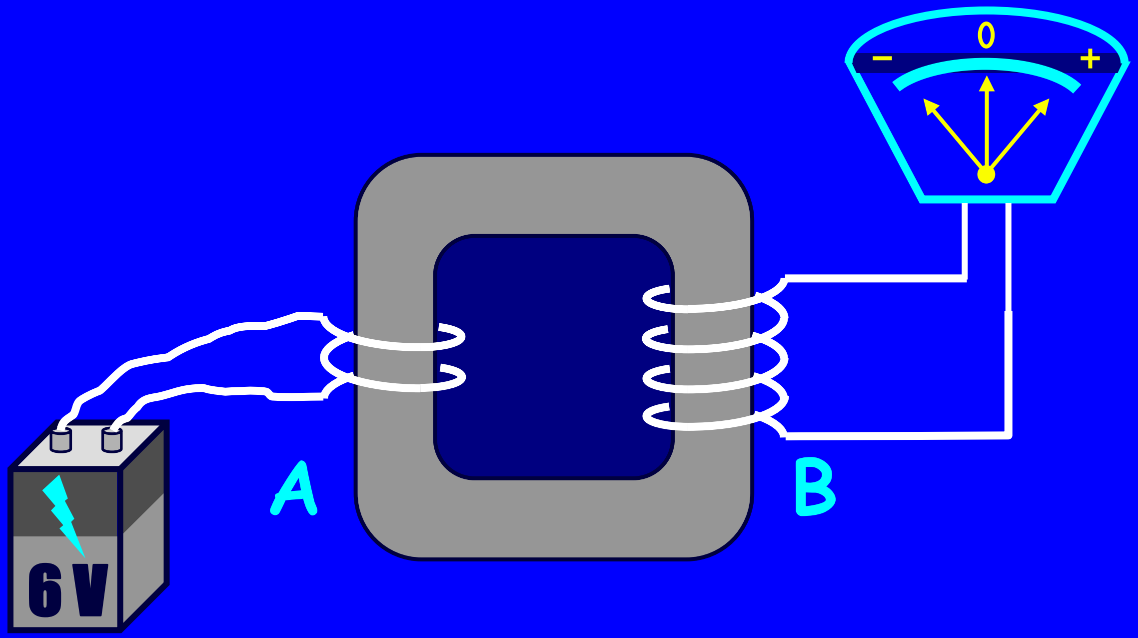
The unknown current is 2 A.



Transformers

A 6 V battery is connected to one side of a transformer. Compared to the voltage drop across coil A, the voltage across coil B is:

1) greater than 6 V
2) 6 V
3) less than 6 V
4) zero

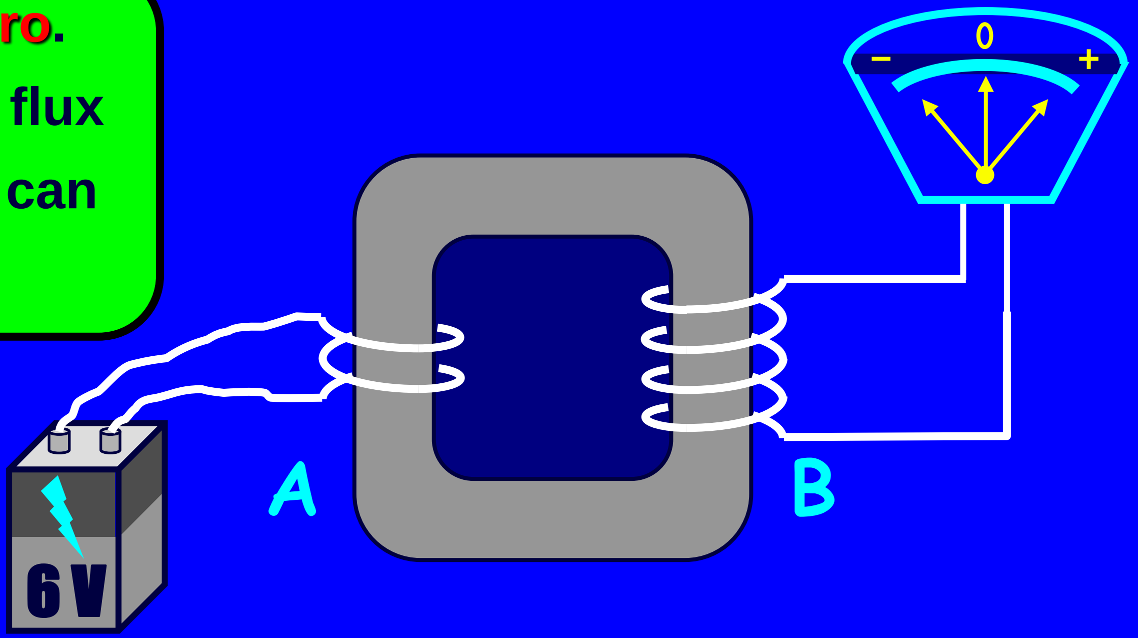


Transformers

A 6 V battery is connected to one side of a transformer. Compared to the voltage drop across coil A, the voltage across coil B is:

1) greater than 6 V
2) 6 V
3) less than 6 V
4) zero

The voltage across B is zero. Only a changing magnetic flux induces an emf. Batteries can provide only dc current.



1. A 250 kVA, 11 000 V/400 V, 50 Hz single-phase transformer has 80turns on the secondary. Calculate: (a) the approximate values of the primary and secondary currents; (b) the approximate number of primary turns; (c) the maximum value of the flux.

2. The maximum flux density in the core of a 250/3000-volt, 50 Hz transformer is 1.2 Wb/m^2. If the EMF per turn is 8 V, determine (i) primary and secondary turns

Voltage regulation of Transformer

$$\text{Voltage regulation} = \frac{\text{no-load voltage} - \text{full-load voltage}}{\text{no-load voltage}}$$

recall $\dfrac{V_s}{V_p} = \dfrac{N_s}{N_p}$

Secondary voltage on no-load $V_2 = V_1\left(\dfrac{N_2}{N_1}\right)$

V_2 is a secondary terminal voltage on full load

Substitute we have

$$\text{Voltage regulation} = \frac{V_1\left(\dfrac{N_2}{N_1}\right) - V_2}{V_1\left(\dfrac{N_2}{N_1}\right)}$$

Transformer Efficiency

Transformer efficiency is defined as (applies to motors, generators and transformers):

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

$$\eta = \frac{P_{out}}{P_{out} + P_{loss}} \times 100\%$$

Types of losses incurred in a transformer:

- Copper I^2R losses
- Hysteresis losses
- Eddy current losses

Therefore, for a transformer, efficiency may be calculated using the following:

$$\eta = \frac{V_S I_S \cos\theta}{P_{Cu} + P_{core} + V_S I_S \cos\theta} x100\%$$

Losses in a transformer

Core or Iron loss:

$$W_h = \eta B_{max}^{1.6} f V \; watt$$

$$W_e = \eta B_{max}^{2} f^{2} t^{2} \;\; watt$$

Copper loss:

$$Total\ Copper\ loss = I_1^2\, R_1 + I_2^2 R_2$$

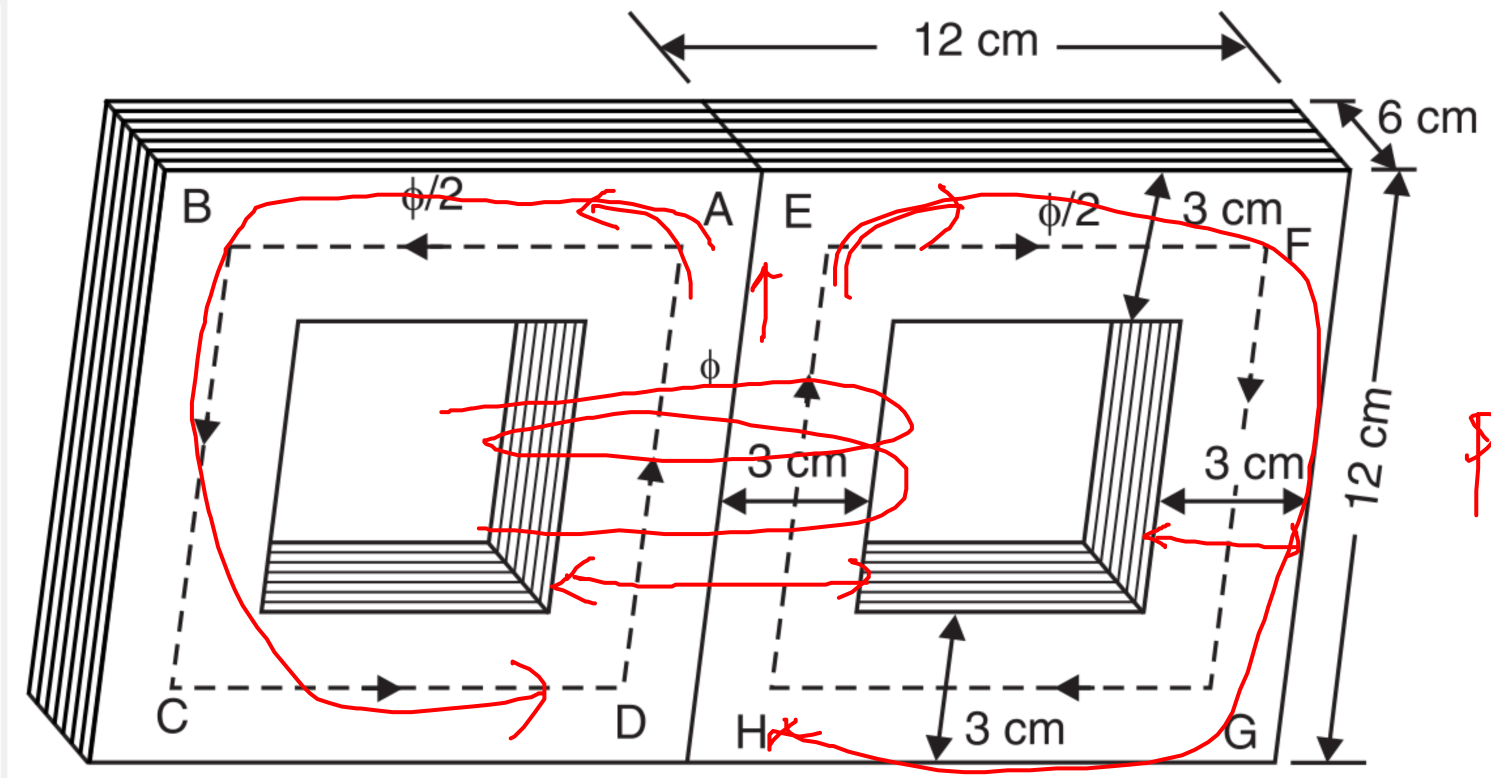
4. In a 25-kVA, 2000/200 V single phase transformer, the iron and full-load copper losses are 350 and 400 W respectively. Calculate the efficiency at unity power factor at full load.

5. In a 25-kVA, 2000/200 V single phase transformer, the iron and full-load copper losses are 350 and 400 W respectively. Calculate the efficiency with unity power factor at half full-load.

Summary

- Ideal Transformer
- Problems
  - EMF equation
  - Magnetic Circuits
  - Efficiency
  - Losses

3. A transformer core made of annealed steel sheet has the form and dimensions shown in Figure. A coil of N turns is wound on the central limb. The average length of magnetic circuit (i.e. path ABCDA or path EFGHE) is 30 cm. Determine the ampere-turns of the coil required to produce a flux density of 1 Wb/m 2 in the central leg. What will be the total amount of flux in the central leg and in each outside leg ? Given that for annealed sheet steel (from B-H curve), H = 200 AT/m at 1 Wb/m 2 .



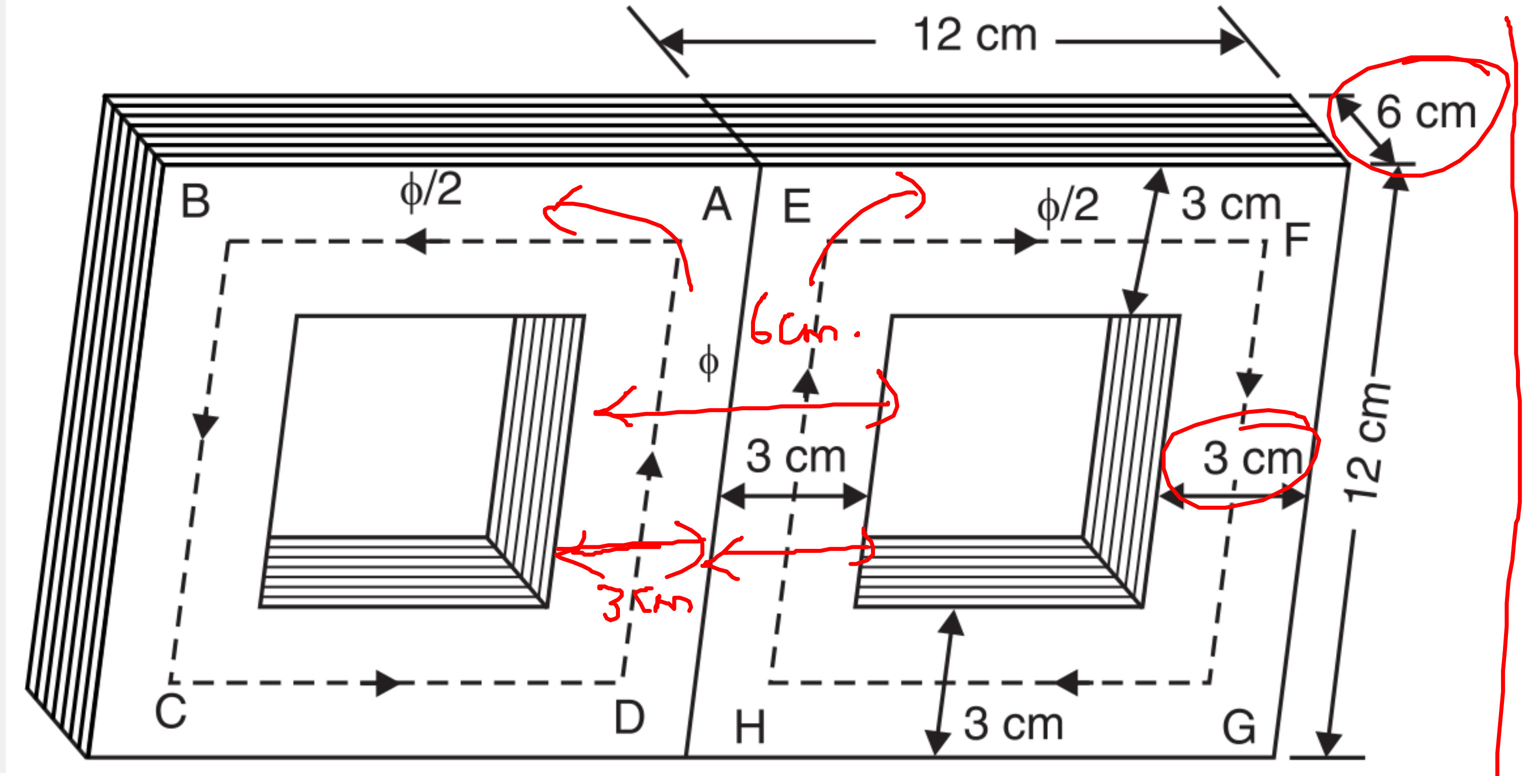
(a) Ampere - turns

(b) flux

Parallel magnetic circuit

$H \cdot l = NI \leftarrow AT$

$200 \times 30 \times 10^{-2} = AT$



(a) $\Rightarrow$ $AT_{req} = H \cdot l$

$= 200 \times 30 \times 10^{-2}$

$= 60 \ AT$

Area $\Rightarrow$ 0.03×0.06

$\Rightarrow$

$B_c = 1 \ wb/m^2$

$B = \dfrac{\phi}{A}$

$\phi = B \times A$

Area of central leg $= 6 \times 10^{-2} \times 6 \times 10^{-2}$

$= 0.0036 \ m^2$

$\phi_c = 1 \times 0.0036$

$\boxed{\phi_c = 0.0036 \ wb}$

$\phi_o = \dfrac{0.0036}{2} = 0.0018 \ wb$