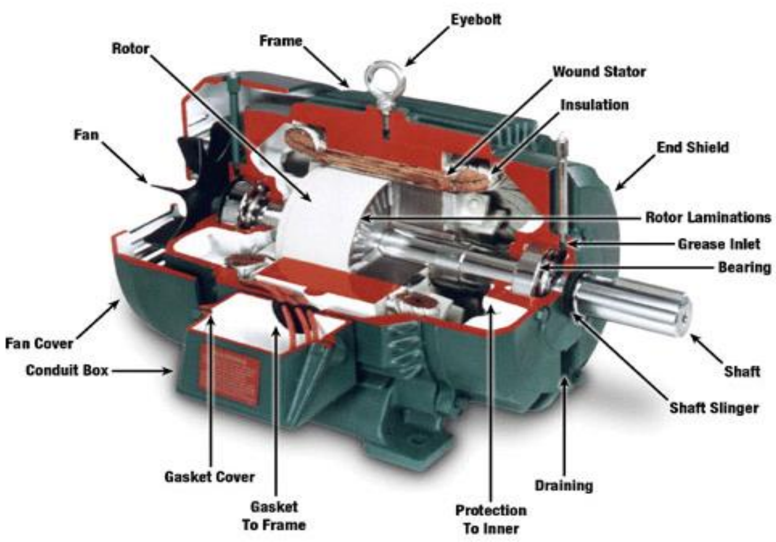
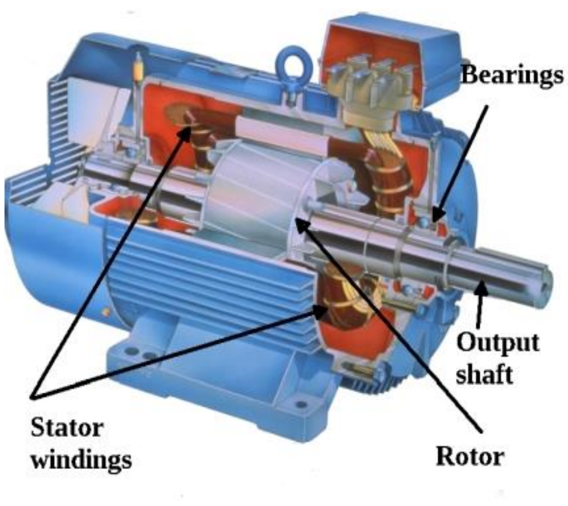
UNIT-III: Fundamentals of Electrical Machines

TRANSFOREMR

DC MACHINE



INDUCTION MOTOR



TRANSFORMER

Principle of Operation: Mutual inductance phenomena in transformer

- Construction
- Working
- Concept of Turns Ratio
- Applications
- Autotransformer
- Instrument transformers

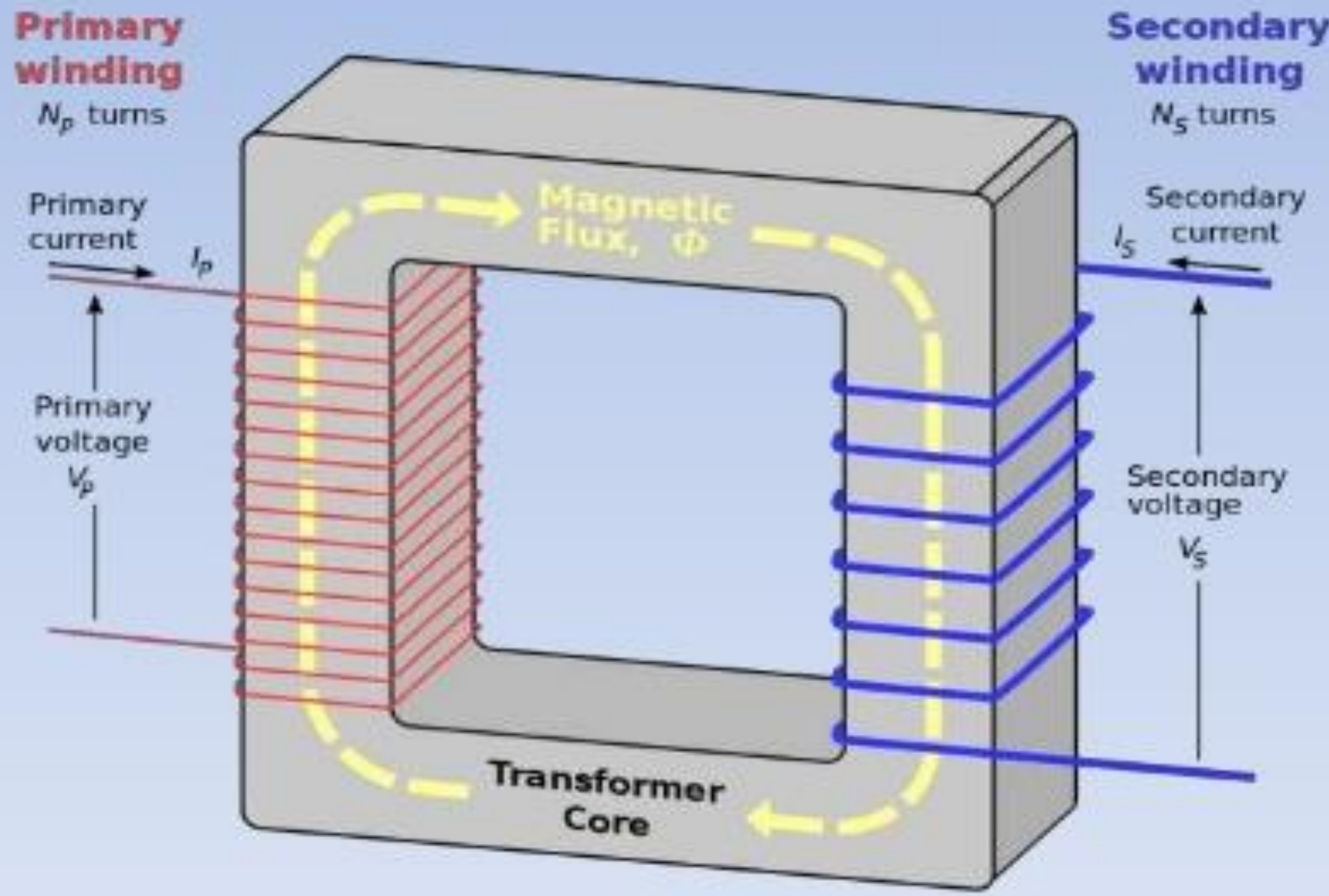
Definition of Transformer

TRANSFORMER: transformer is a static device which transforms electrical energy from one circuit to another without any direct electrical connection and with the help of mutual induction between two windings. It transforms power from one circuit to another without changing its frequency but may be in different voltage level.

In Brief, A **transformer** is a static electrical device that transfers electrical energy between two or more circuits through electromagnetic induction.

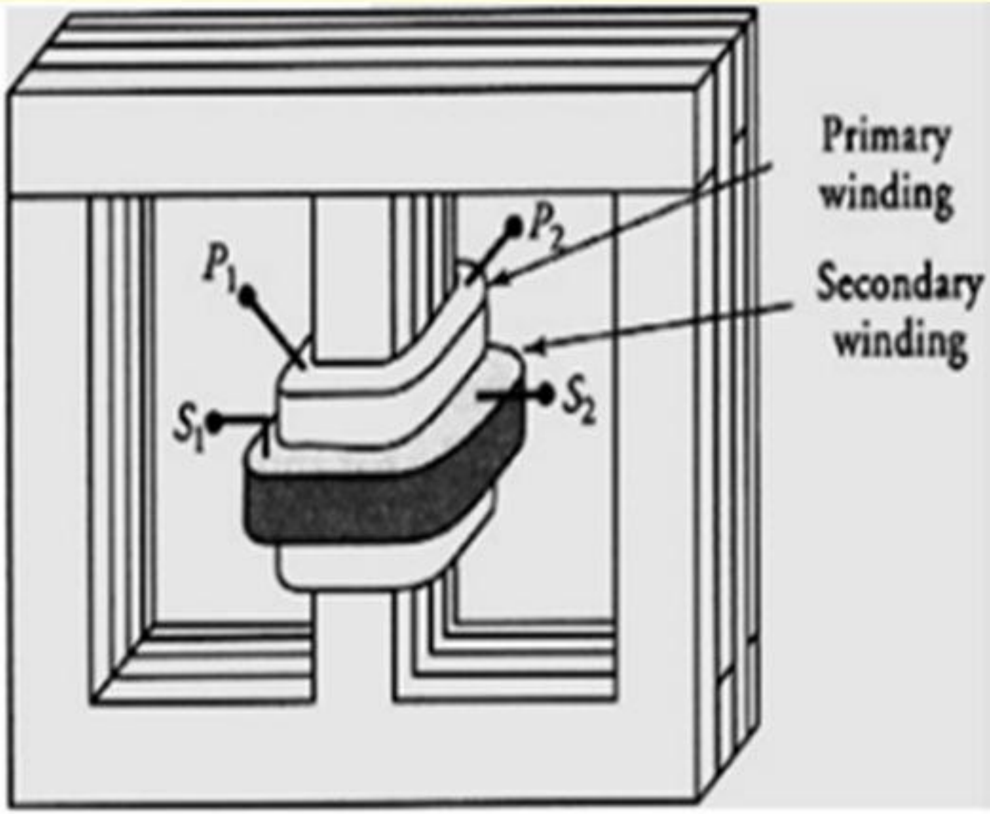
Electromagnetic or magnetic **induction** is the production of an electromotive force (i.e., voltage) across an electrical conductor in a changing magnetic field

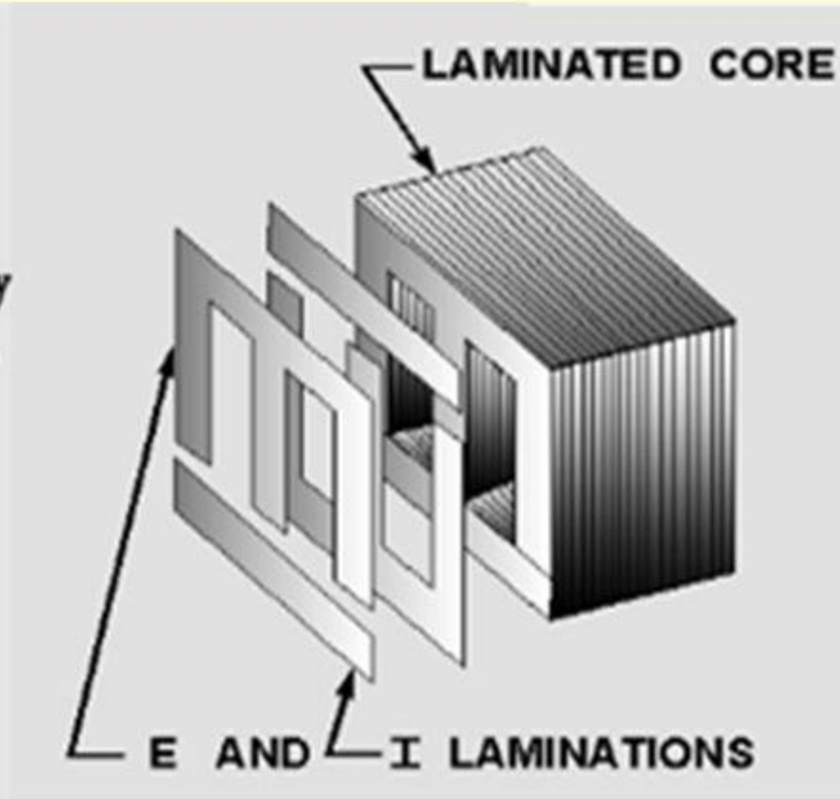
Transformer Construction



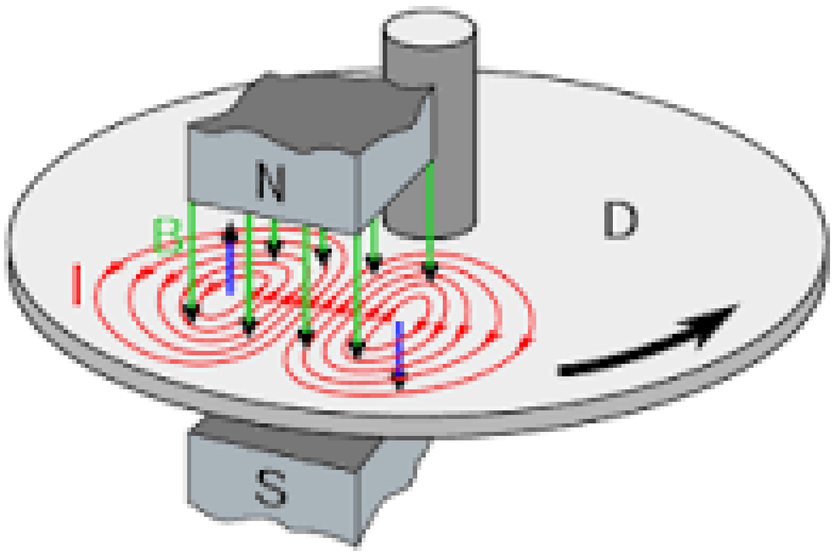
Transformer Construction

Core is made up of laminations to reduce the eddy current losses.
The thickness of laminations is usually 0.4mm.

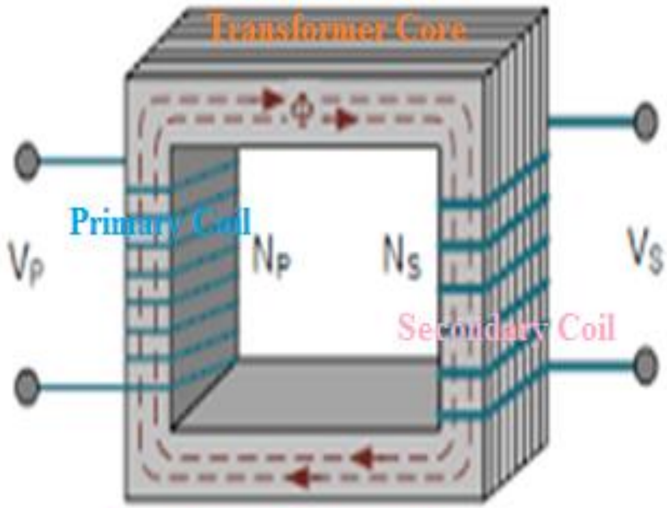




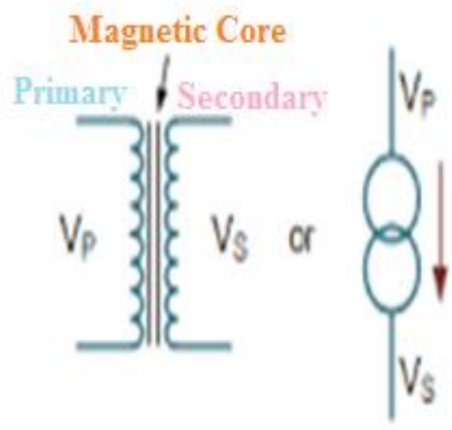
- Eddy currents are loops of electrical current induced within conductors by a changing magnetic field in the conductor due to Faraday's law of induction.



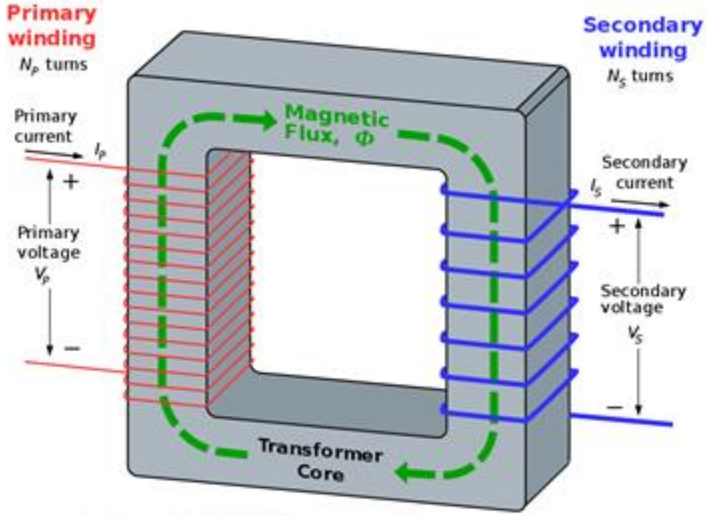
TRANSFORMER SYMBOLS



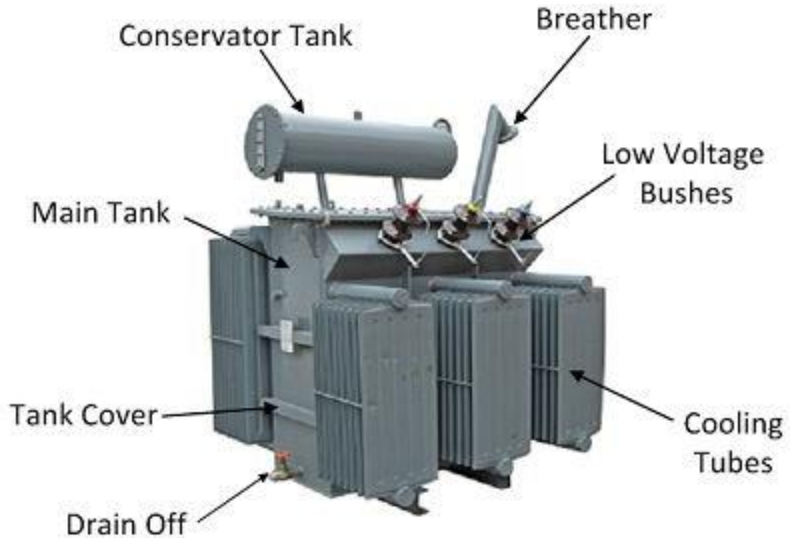
Transformer Construction



Transformer Symbol

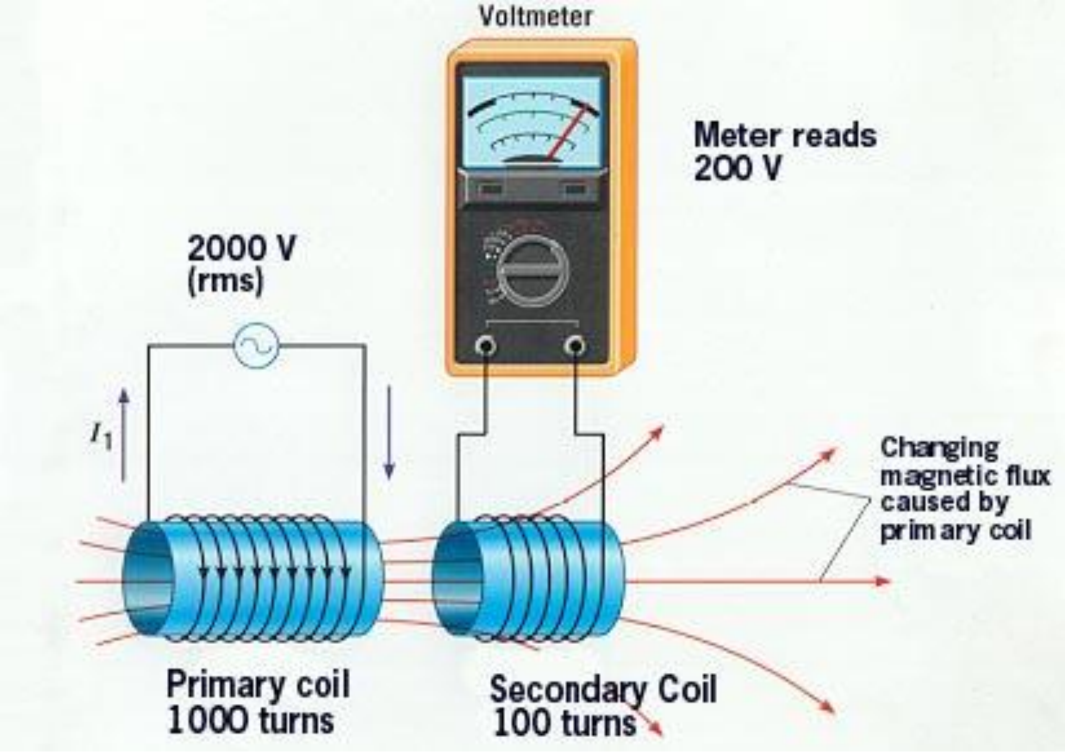


Inside Transformer



Outside Transformer

Principle of operation



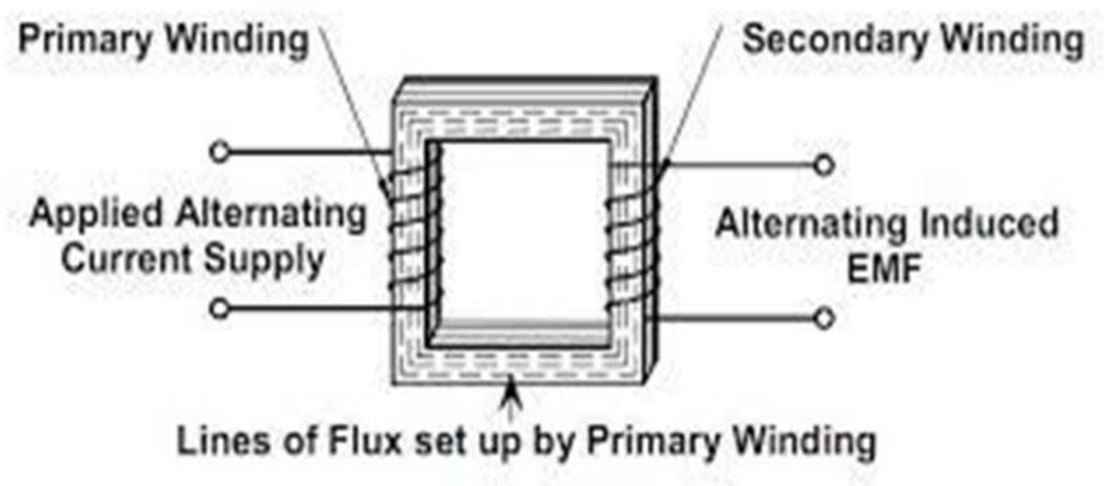
It is based on principle of MUTUAL INDUCTION.

According to which an e.m.f. is induced in a coil when current in the neighbouring coil changes.

PRINCIPLE OF TRANSFORMER

It works on the **principle** of Electromagnetic induction.

The current flowing in the primary winding of the transformers creates a magnetic field, magnetic flux flows to the secondary side of the transformers, which induces EMF in the winding and current flows when the circuit is closed.



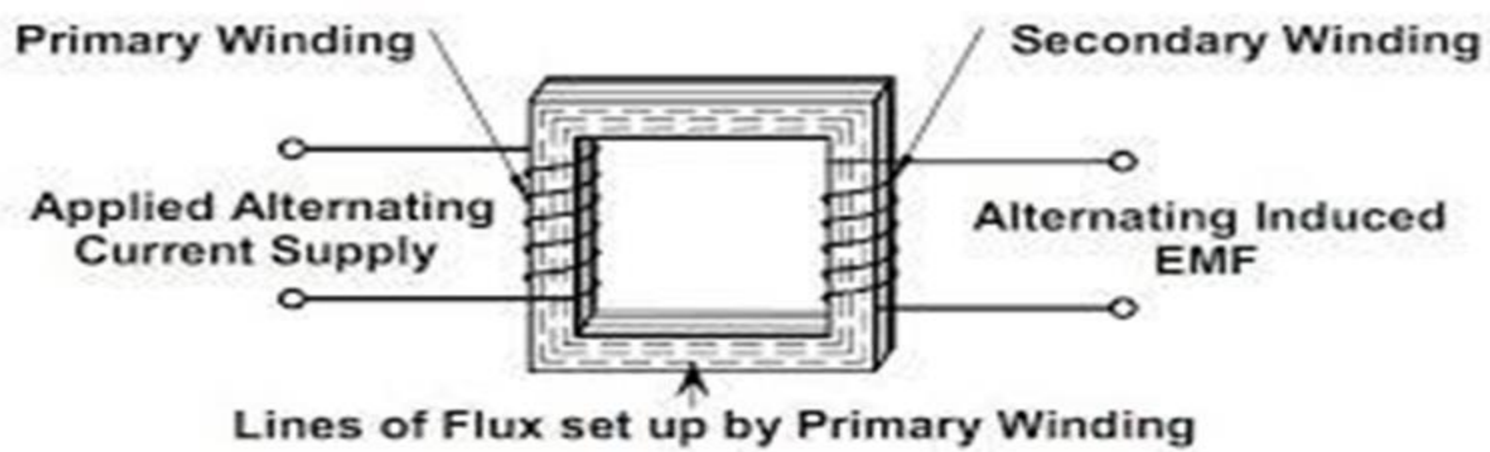
A varying current in one coil of the transformer produces a varying magnetic field, which in turn induces a varying electromotive force (emf) or "voltage" in a second coil.

Principle of Transformer

- The transformer works on the principle of mutual induction

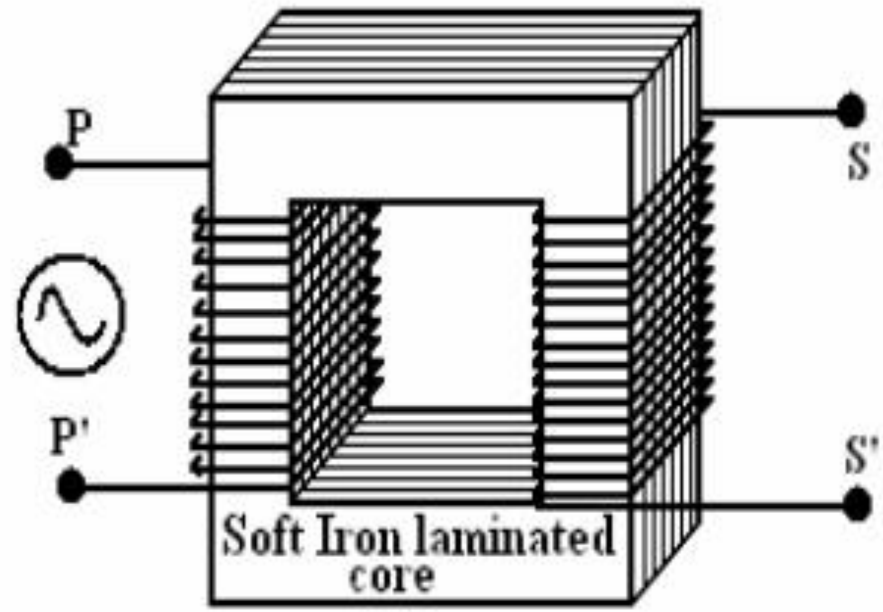
"The principle of mutual induction states that when the two coils are inductively coupled and if the current in coil change uniformly then the e.m.f. induced in the other coils. This e.m.f can drive a current when a closed path is provide to it."

- When the alternating current flows in the primary coils, a changing magnetic flux is generated around the primary coil.
- The changing magnetic flux is transferred to the secondary coil through the iron core
- The changing magnetic flux is cut by the secondary coil, hence induces an e.m.f in the secondary coil



Working of a transformer

1. When current in the primary coil changes being alternating in nature, a changing magnetic field is produced
2. This changing magnetic field gets associated with the secondary through the soft iron core
3. Hence magnetic flux linked with the secondary coil changes.
4. Which induces e.m.f. in the secondary.



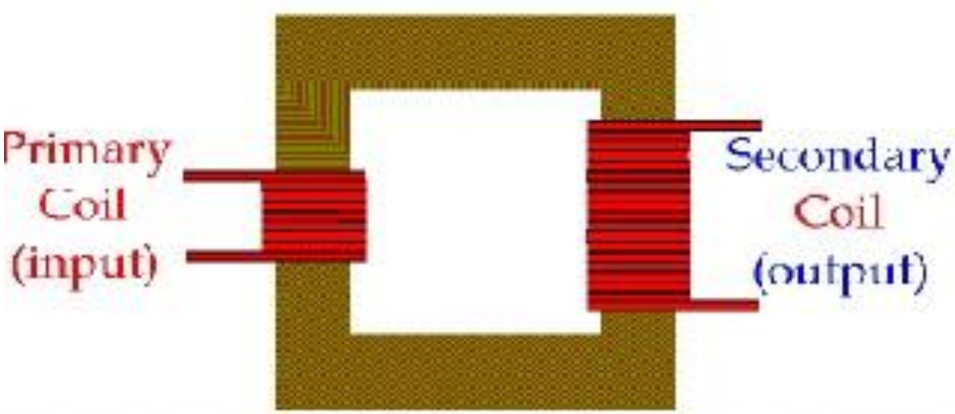
Types of transformers

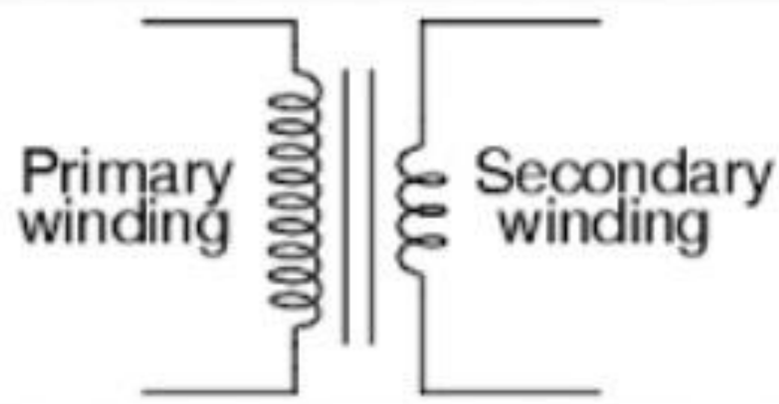
- Step up transformers

In step up transformers no. of turns of primary windings are less as compared to no. of turns of secondary windings .

- Step down transformers

In step down transformers no. of turns of primary windings are more as compared to no. of turns of secondary windings

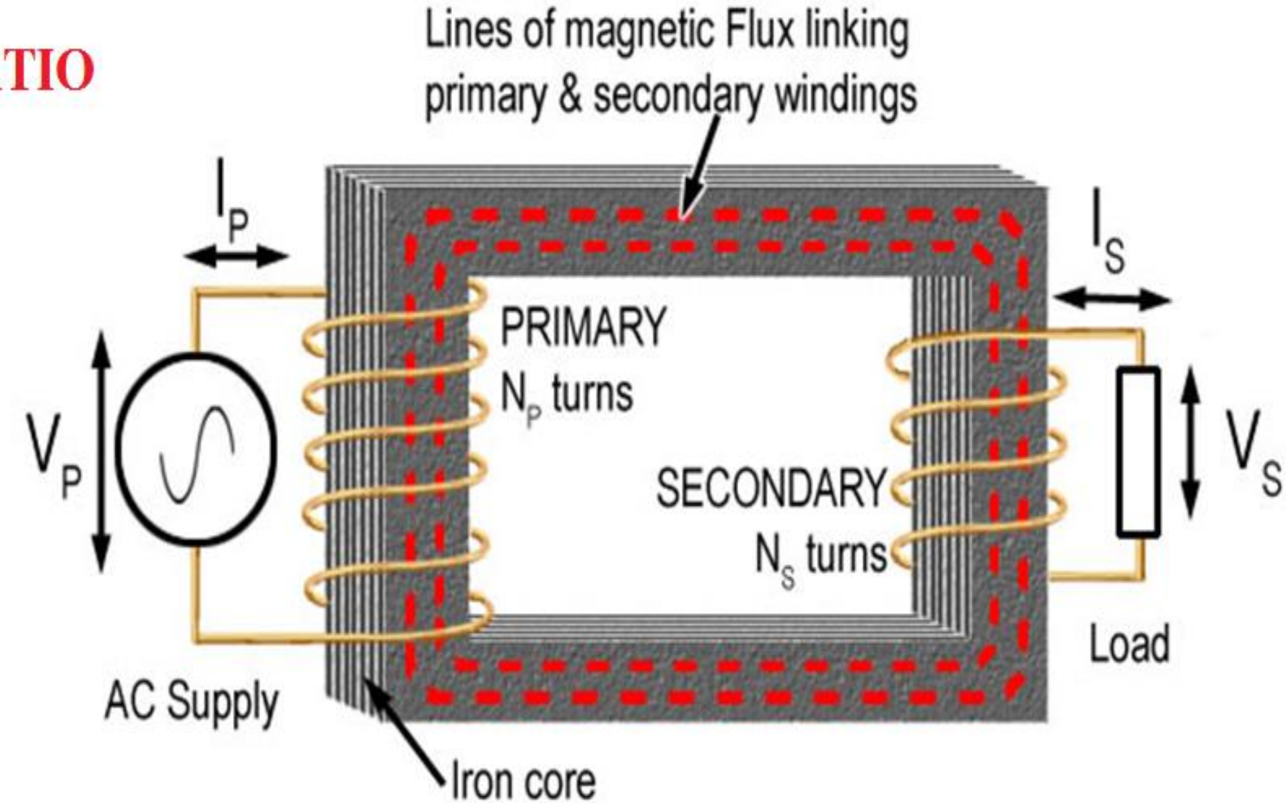




CONCEPT OF TURN RATIO

$$\boxed{a = \frac{n_1}{n_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}}$$

where: a = turns ratio of transformer
n_1 = number of turns on primary
n_2 = number of turns on secondary
V_1 = primary voltage
V_2 = secondary voltage
I_1 = primary current
I_2 = secondary current



$$\frac{\text{The number of primary turns } N_P}{\text{The number of secondary turns } N_S} = \frac{\text{The primary voltage } V_P}{\text{The secondary voltage } V_S}$$

$$\frac{\text{The number of secondary turns } N_S}{\text{The number of primary turns } N_P} = \frac{\text{The primary current } I_P}{\text{The secondary current } I_S}$$

EXAMPLE: A transformer has 400 turns on the primary and 1200 turns on the secondary. If 120 volts of AC current are applied across the primary, what voltage is induced into the secondary?

Given	**Solution**
$E_S = ?$	$\frac{E_S}{E_P} = \frac{N_S}{N_P}$
$E_P = 120\ \text{V}$	
$N_S = 1200$ turns	$\frac{E_S}{120} = \frac{1200}{400}$
$N_P = 400$ turns	
	$E_S = 360\ \text{V}$

EMF Equation

Consider a sinusoidally varying voltage V_1 applied to the primary of the transformer shown in Fig. 13.1*a*. Due to this voltage, a sinusoidally varying magnetic flux is set up in the core, which can be represented as

$$\Phi = \Phi_m \sin \omega t = \Phi_m \sin 2\pi f t \tag{13.1}$$

where Φ_m is the peak value of the flux and f is the frequency of sinusoidal variation of flux. As per the law of electromagnetic induction, the induced emf in a winding of N turns is given as

$$e = -N\frac{d\Phi}{dt} = -N\frac{d}{dt}(\Phi_m \sin \omega t) = -N\omega\Phi_m \cos \omega t = \omega N \Phi_m \sin(\omega t - \pi/2) \tag{13.2}$$

Thus, the peak value of the induced emf is $E_m = \omega N \Phi_m$. Therefore, the rms value of the induced emf E is given as

$$E = \frac{E_m}{\sqrt{2}} = \frac{\omega N \Phi_m}{\sqrt{2}} = \frac{2\pi f N \Phi_m}{\sqrt{2}} = 4.44 fN\,\Phi_m$$

or

$$\boxed{E = 4.44 fN\Phi_m} \tag{13.3}$$

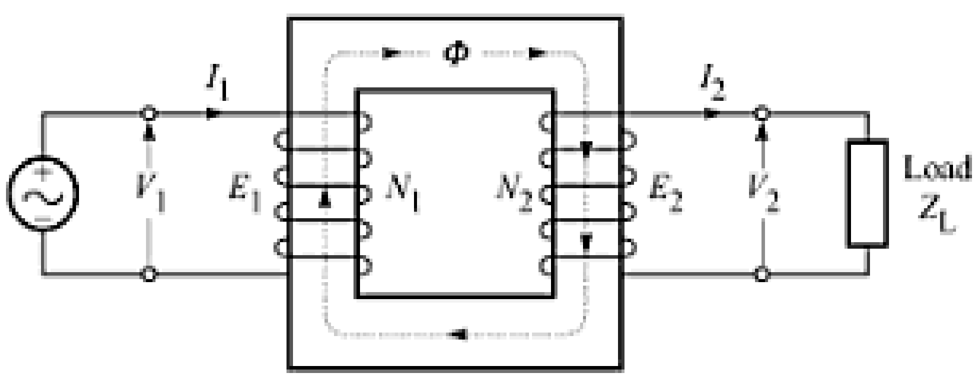
This equation, known as ***emf equation of transformer***, can be used to find the emf induced in any winding (primary or secondary) linking with flux Φ.

Ideal tranformer

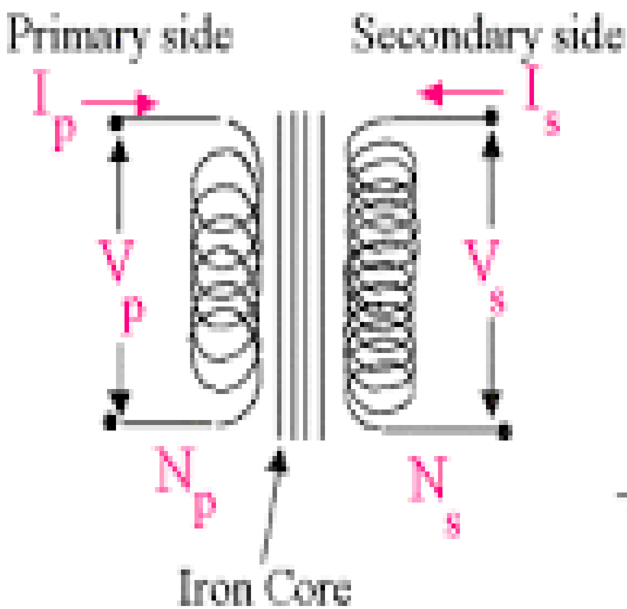
Condition of ideal transformer

- The core of the transformer has no losses
- The resistance of its windings is zero, hence no I^2R losses in the windings
- Entire flux in the core links both the windings

Consider an ideal transformer whose secondary side connected to load and primary to ac supply



(a) The circuit.



$$\frac{V_s}{V_p} = \frac{N_s}{N_p},$$

But,

$$\frac{I_s}{I_p} = \frac{N_p}{N_s}$$

If the purpose is to increase voltage, the secondary coil must have more turns and therefore a thinner wire. Note that at best the output power equals the input power. Ideally, $P_{out} = P_{in}$, or $V_s I_s = V_p I_p$

Writing as proportions : $\dfrac{V_s}{V_p} = \dfrac{I_p}{I_s}$

This is true for an ideal transformer only .

Question

- The primary of 50 Hz step-down transformer has 480 turns and is fed from 6400 V supply. Find (a) the peak value of the flux produced in the core
- (b) the voltage across the secondary winding if it has 20 turns.

Solution

(a) Using Eq. 13.3, we get

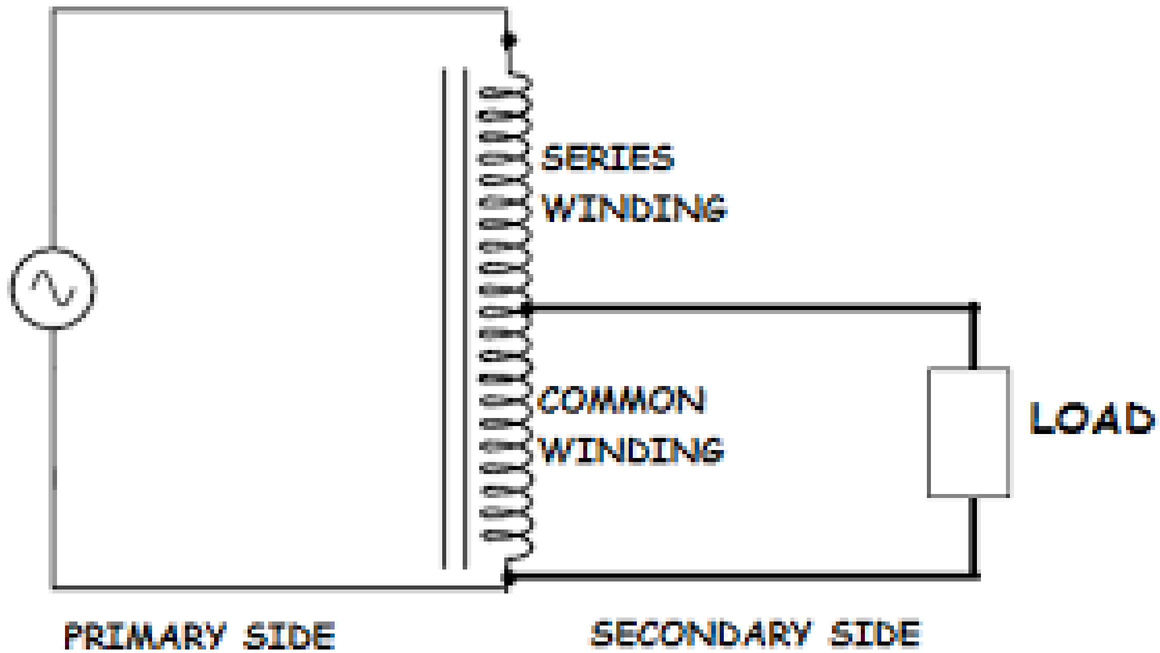
$$\Phi_m = \frac{E}{4.44\, f N_1} = \frac{6400}{4.44 \times 50 \times 480} = 0.06 \text{ Wb} = \mathbf{60\ mWb}$$

(b) The voltage induced in the secondary winding is given as

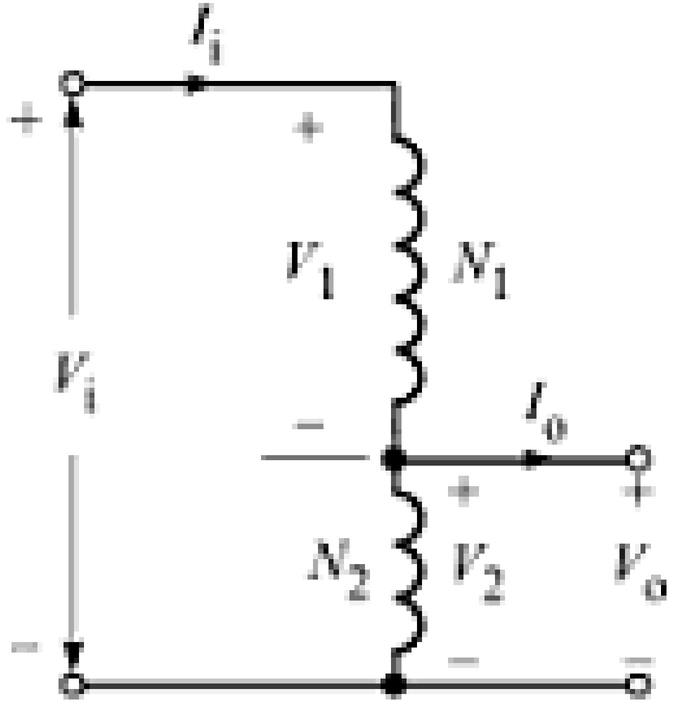
$$E = 4.44\, f N_2\, \Phi_m = 4.44 \times 50 \times 20 \times 0.06 = \mathbf{266.4V}$$

Auto-Transformer

An Auto-transformer is an electrical transformer with only one winding.



Autotransformer



- It is a special transformer connection that is useful in power system, motor starters,and other applications.

- The secondary and the primary windings are connected in series for the new primary, the secondary is the new secondary
- They are not electrically isolated from each other. V2=Vo

$$V_i = V_1 + V_2 = \frac{N_1}{N_2}\, V_2 + V_2 = \frac{N_1 + N_2}{N_2}\, V_o$$

$$V_o = \frac{N_2}{N_1 + N_2} V_i$$

Hence, the new turns-ratio becomes $N_2 : (N_1 + N_2)$.

Advantages Of Autotransformers

- An autotransformer requires less Cu than a two-winding transformer of similar rating.
- An autotransformer operates at a higher efficiency than a two-winding transformer of similar rating.
- An autotransformer has better voltage regulation than a two-winding transformer of the same rating.
- An autotransformer has smaller size than a two-winding transformer of the same rating.
- An autotransformer requires smaller exciting current than a two-winding transformer of the same rating.

The auto transformer is cheaper than the ordinary transformer because of single winding uses less copper than the two winding.

Some special Transformers

- **INSTRUMENT TRANSFORMER:**
- They are high accuracy class electrical devices used to isolate or transform voltage or current levels
- The most common usage of instrument transformers is to operate instruments or metering from high voltage or high current circuits, safely isolating secondary control circuitry from the high voltages or currents.
- **Relays** control one electrical circuit by opening and closing contacts in another circuit.

Instrument Transformers

- The original magnitude can be determined by just multiplying the result with the transformation ratio. Such specially constructed transformers with accurate turns ratio are called as **Instrument transformers**.

- These instruments transformers are of two types –

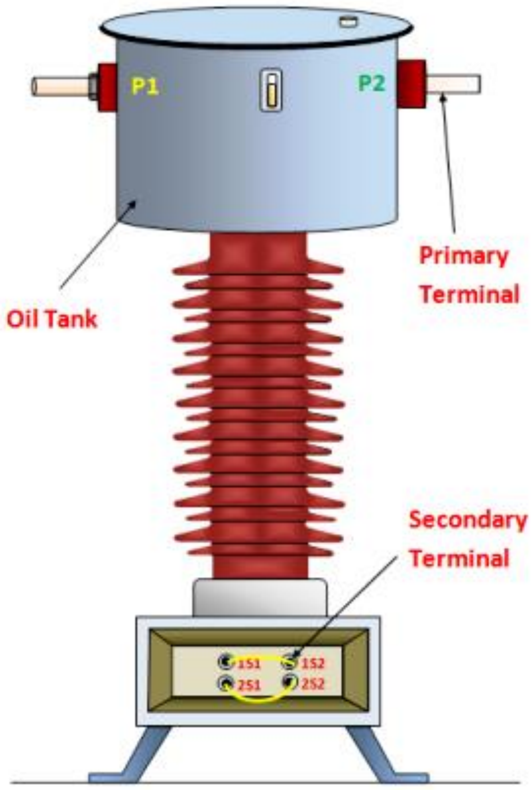
  (i) **Current Transformers (CT)** and

  (ii) **Potential Transformers (PT)**.

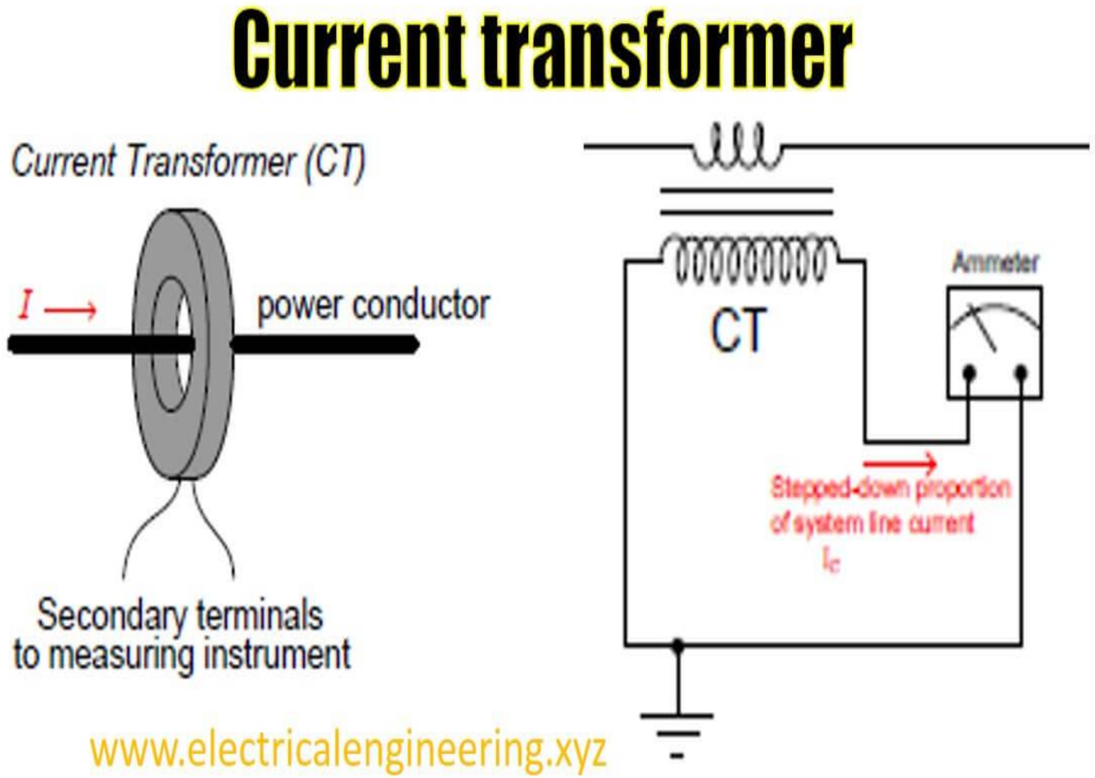
Current Transformers

Construction of C.T.:

- C.T. has a primary coil of one or more turns made of thick wire connected in series with the line whose current is to be measured.
- The secondary consists of a large number of turns made of fine wire and is connected across an ammeter



Live Tank Current Transformer



Potential Transformers

Construction and working of P.T.:

Construction

- A potential transformer has many primary winding turns but few number of secondary winding turns that makes it a step-down transformer.
- A Voltmeter is connected to the secondary winding is usually a voltmeter of 150 V.

Working (Measurement):

- Primary terminals are connected in parallel across the line to which the voltage is to be measured.
- The voltmeter reading gives the transformed value of the voltage across the secondary terminals.

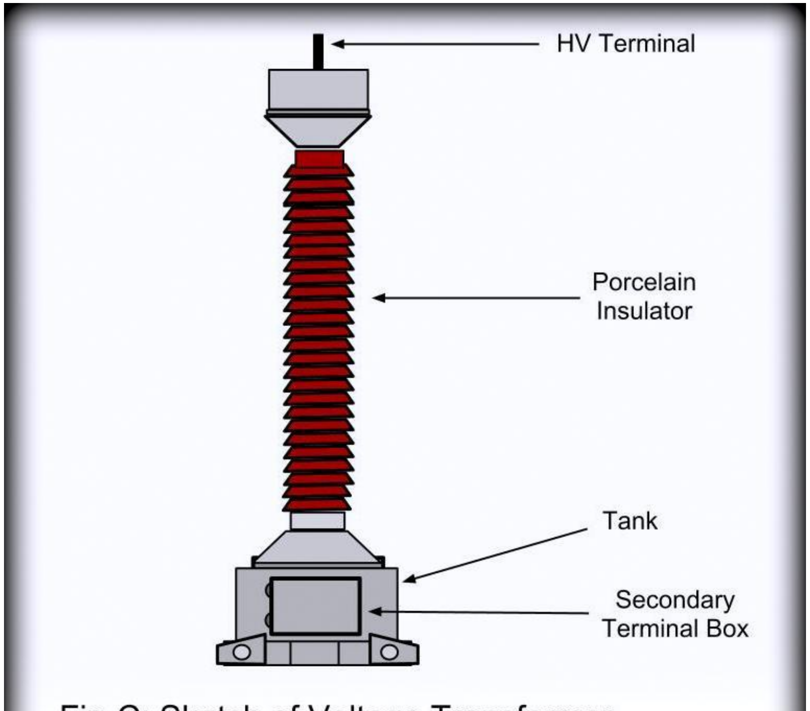
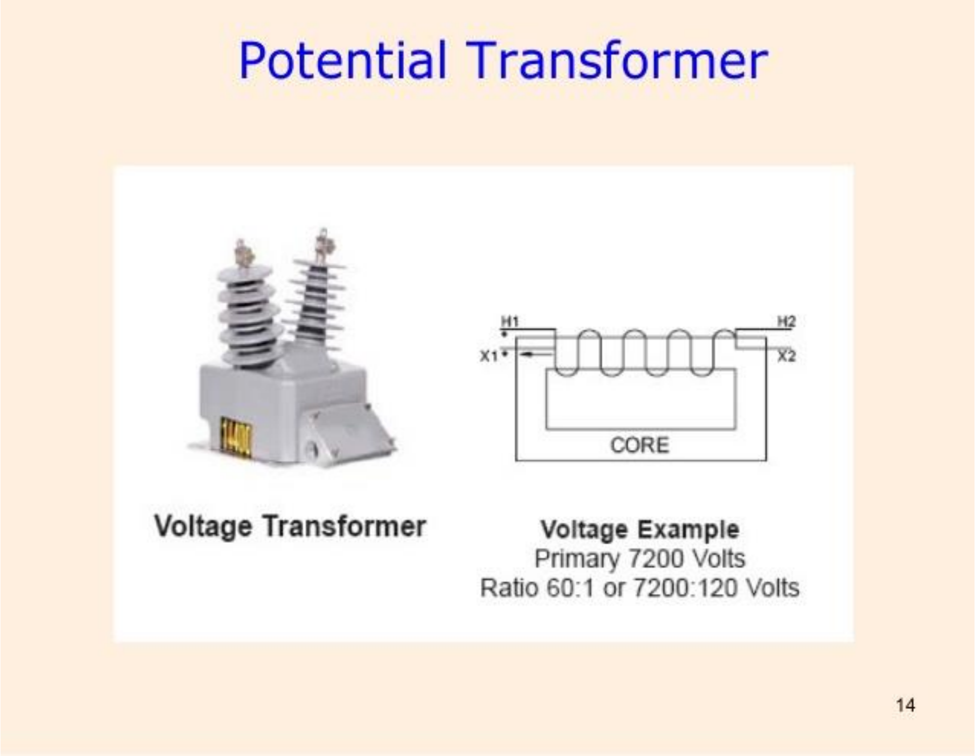


Fig-C: Sketch of Voltage Transformer

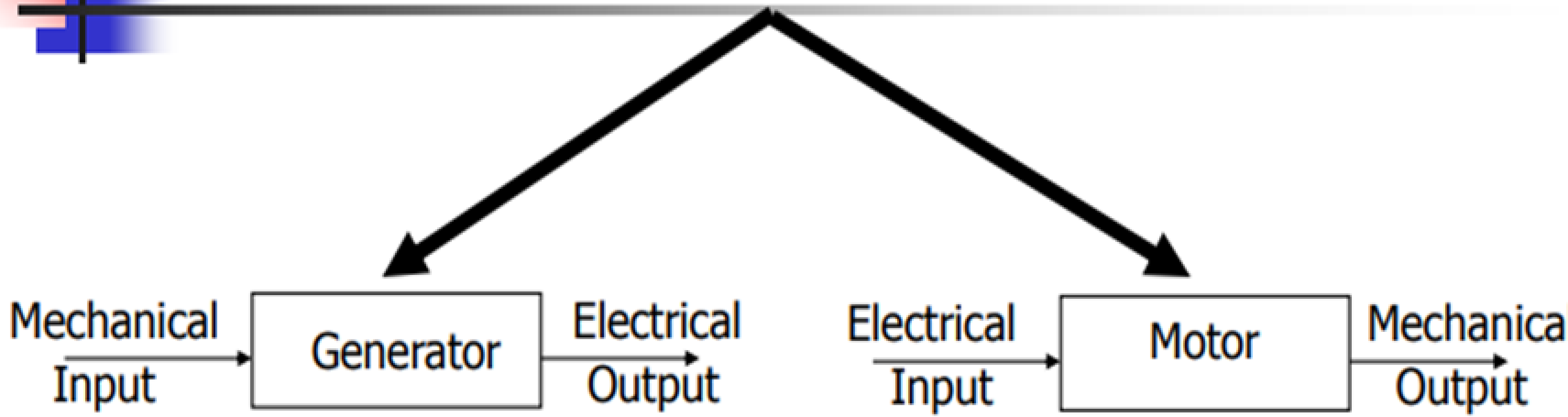


DC MACHINES

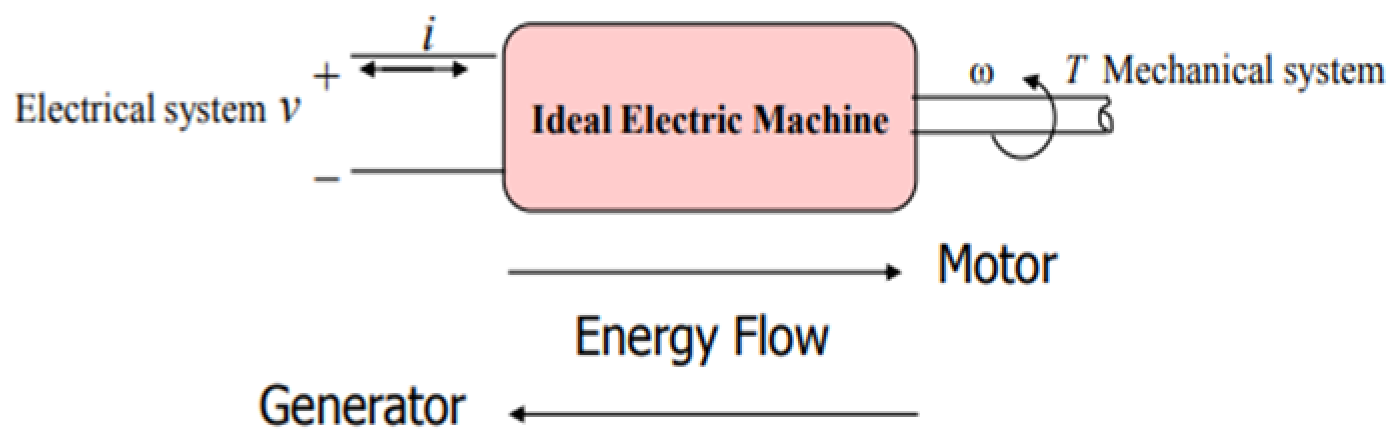
- **DC MOTOR**
- **DC GENERATOR**

- ❑ Working principles
- ❑ Classification
- ❑ Starting of DC Machines
- ❑ Speed control of DC Motor
- ❑ Applications of dc motors

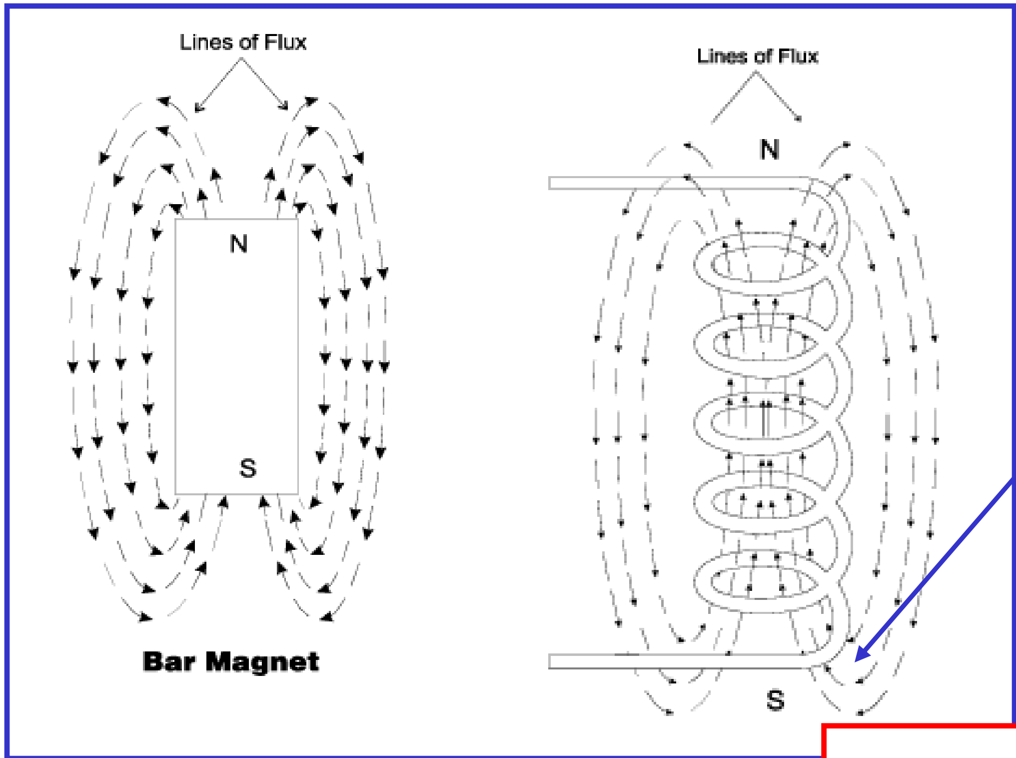
Electric Machine



Electromechanical Energy Conversion



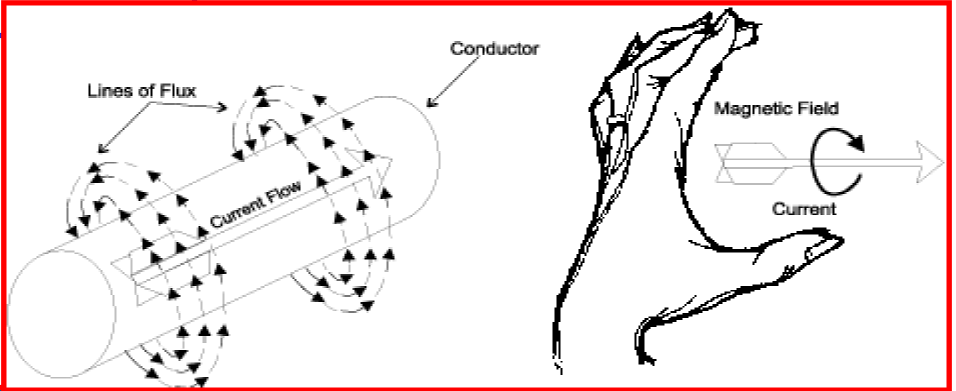
Review of magnetism



Lines of flux define the magnetic field and are in the form of concentric circles around the wire.

The magnetic lines around a current carrying conductor leave from the N-pole and re-enter at the S-pole.

"Left Hand Rule" states that if you point the thumb of your left hand in the direction of the current, your fingers will point in the direction of the magnetic field.



The flow of electrical current in a conductor sets up concentric lines of magnetic flux around the conductor.

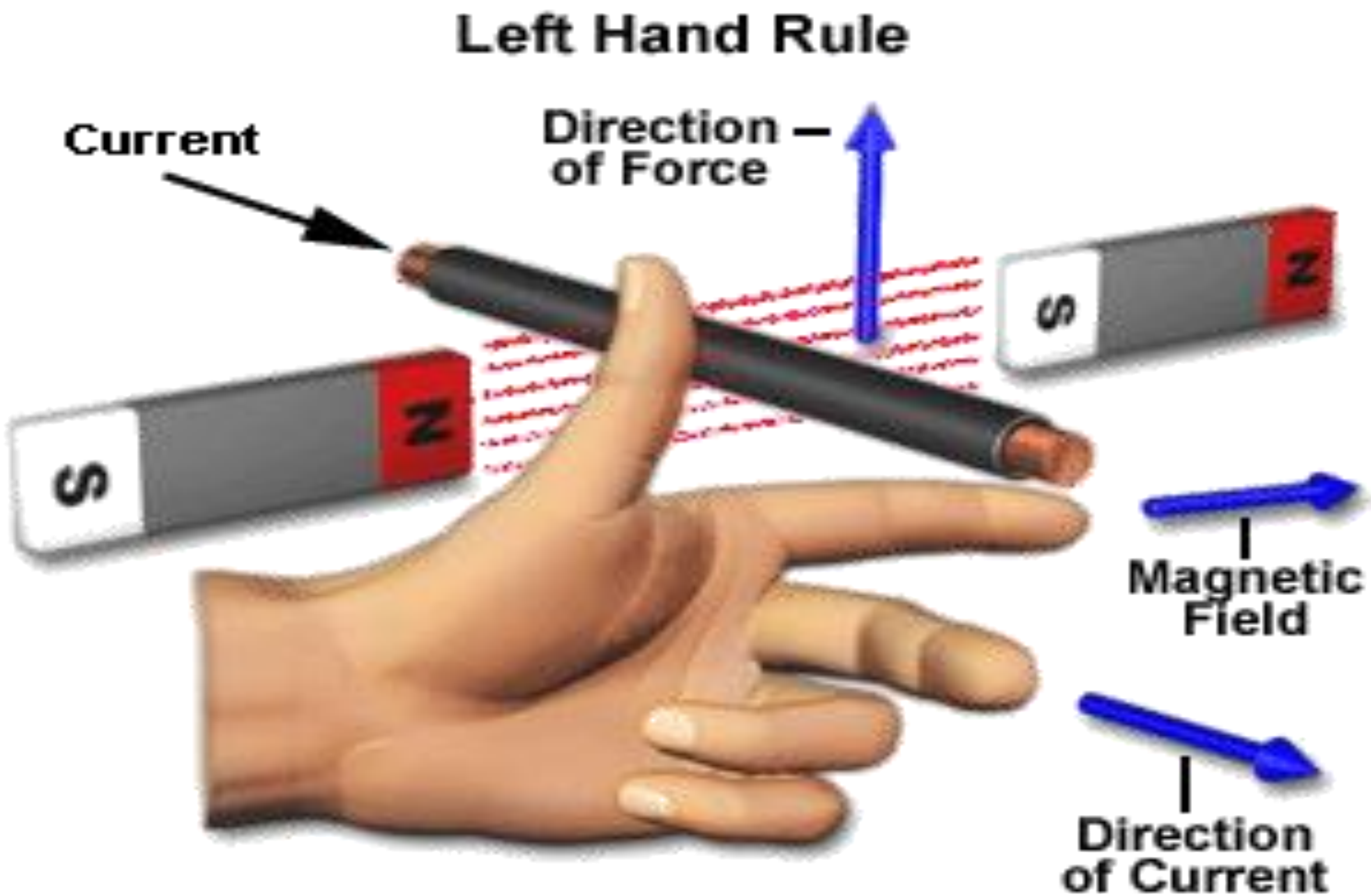
Fleming's left hand rule

- Used to determine the direction of force acting on a current carrying conductor placed in a magnetic field .
- The middle finger , the fore finger and thumb of the left hand are kept at right angles to one another .

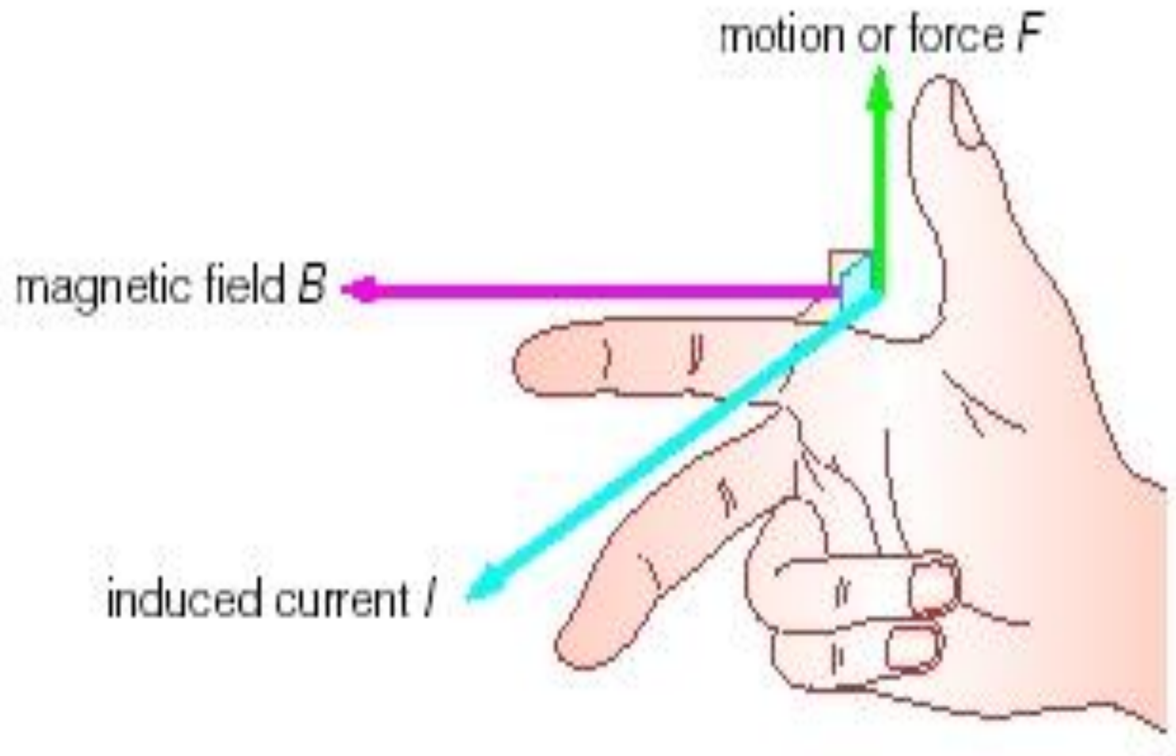
- The middle finger represent the direction of current
- The fore finger represent the direction of magnetic field
- The thumb will indicate the direction of force acting on the conductor .

This rule is used in motors.

Fleming's left hand rule

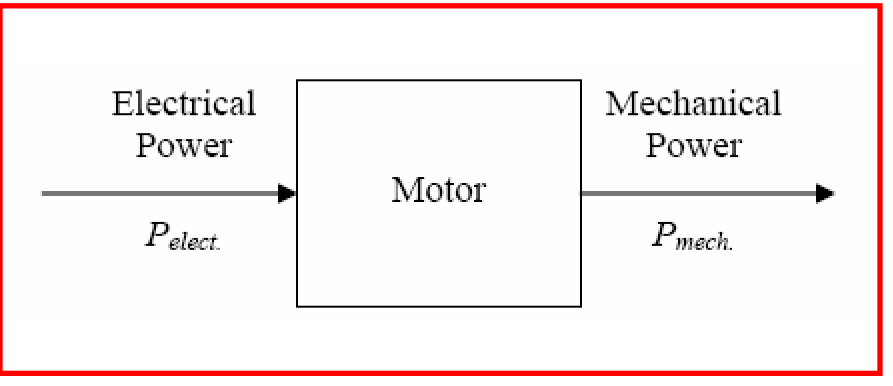


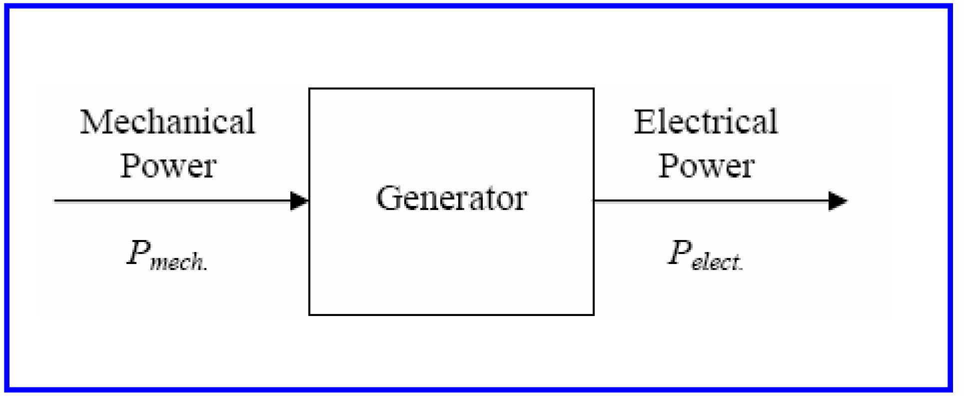
Fleming's Right hand rule



What are DC Machines?

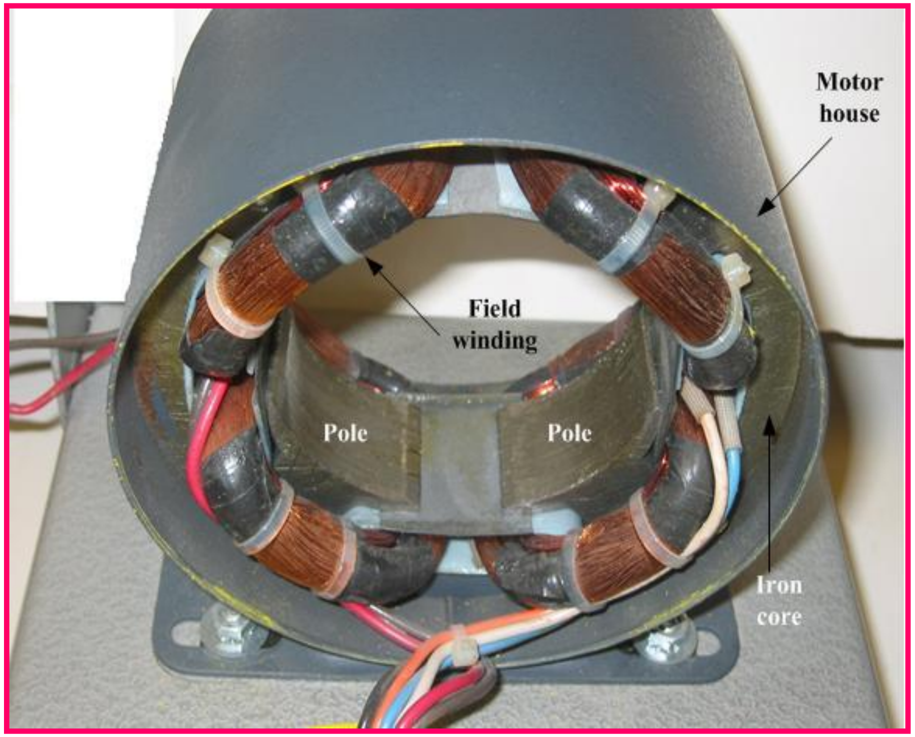
- *Are DC generators that convert mechanical energy to electric energy.*
- *Are DC motors that convert electric energy to mechanical energy.*



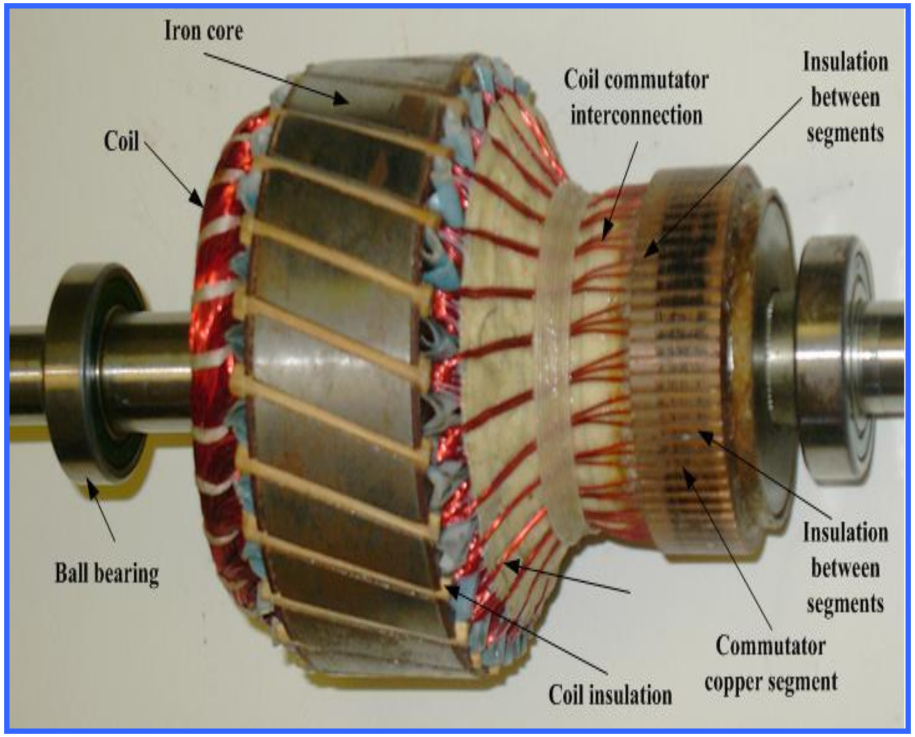


- DC machine can be used as a **motor** or as a **generator**.
- DC Machine is most often used for a motor.

CONSTRUCTION OF DC MACHINES



DC motor stator



Rotor of a dc motor

Main parts of DC machine

Yoke: **It is the outermost cylinderical part which serves two purposes. First it act as a supporting frame for machine, and second it provides the path for the magnetic flux.**

Poles: The pole cores are fixed inside the yoke by bolts **The poles are mounted on an iron core that provides a closed magnetic circuit.**

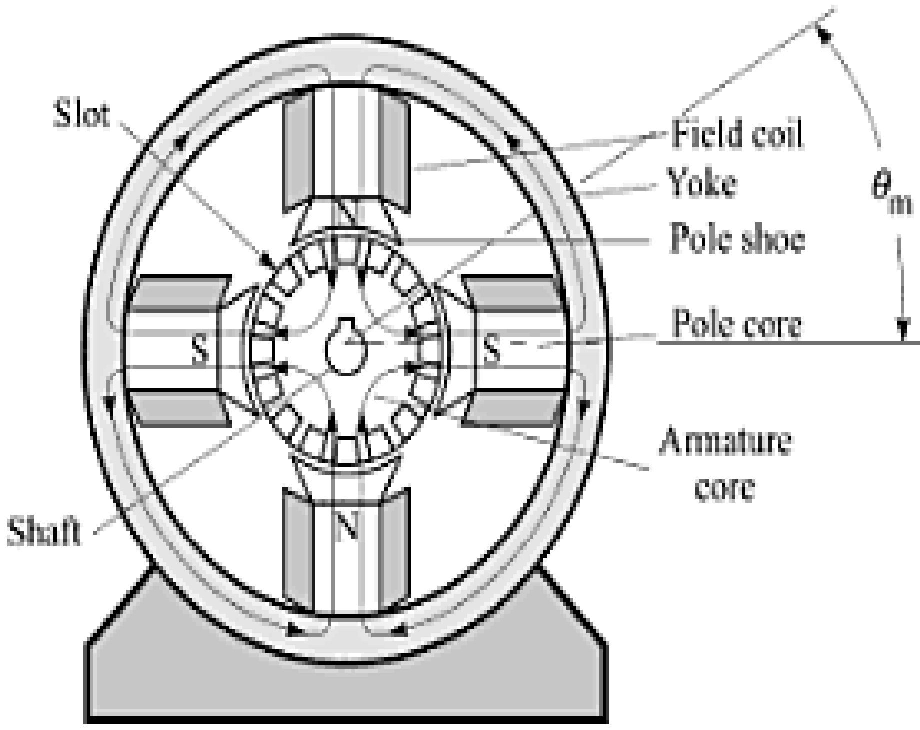


Fig. 16.1 *Main parts of a dc machine.*

Field coils: The field coils are wound on the pole cores and are supported by the pole shoe. All coils are identical and are connected in series such that on excitation by a dc source alternating north and south poles are made. Thus the machine has even number of poles.

Rotor:

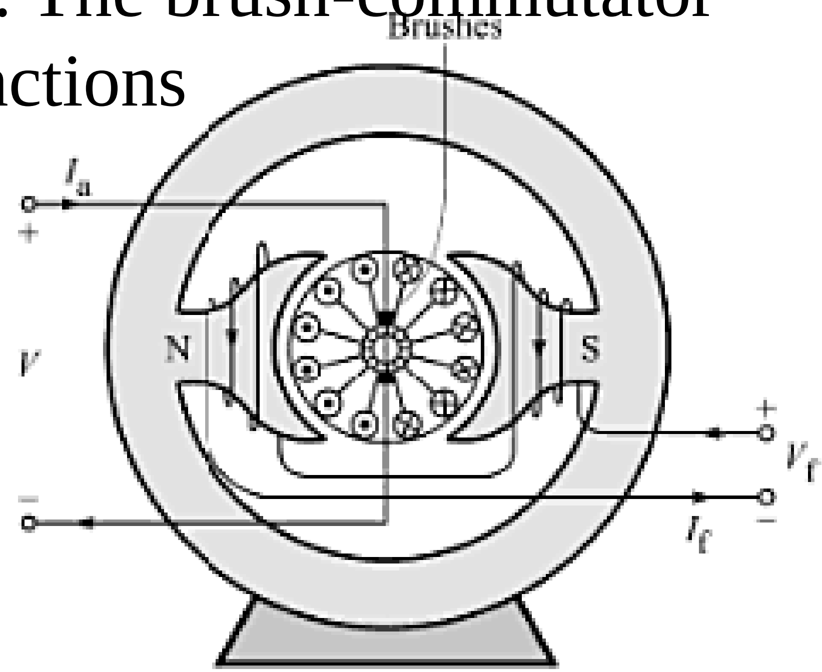
The rotor is the inner cylindrical part having armature and commutator-brush arrangement.

1. Armature: The armature consist of steel laminations, each of 0.4-0.6 mm thick, insulated from one another. The purpose of laminating the core is to reduce eddy- current loss.

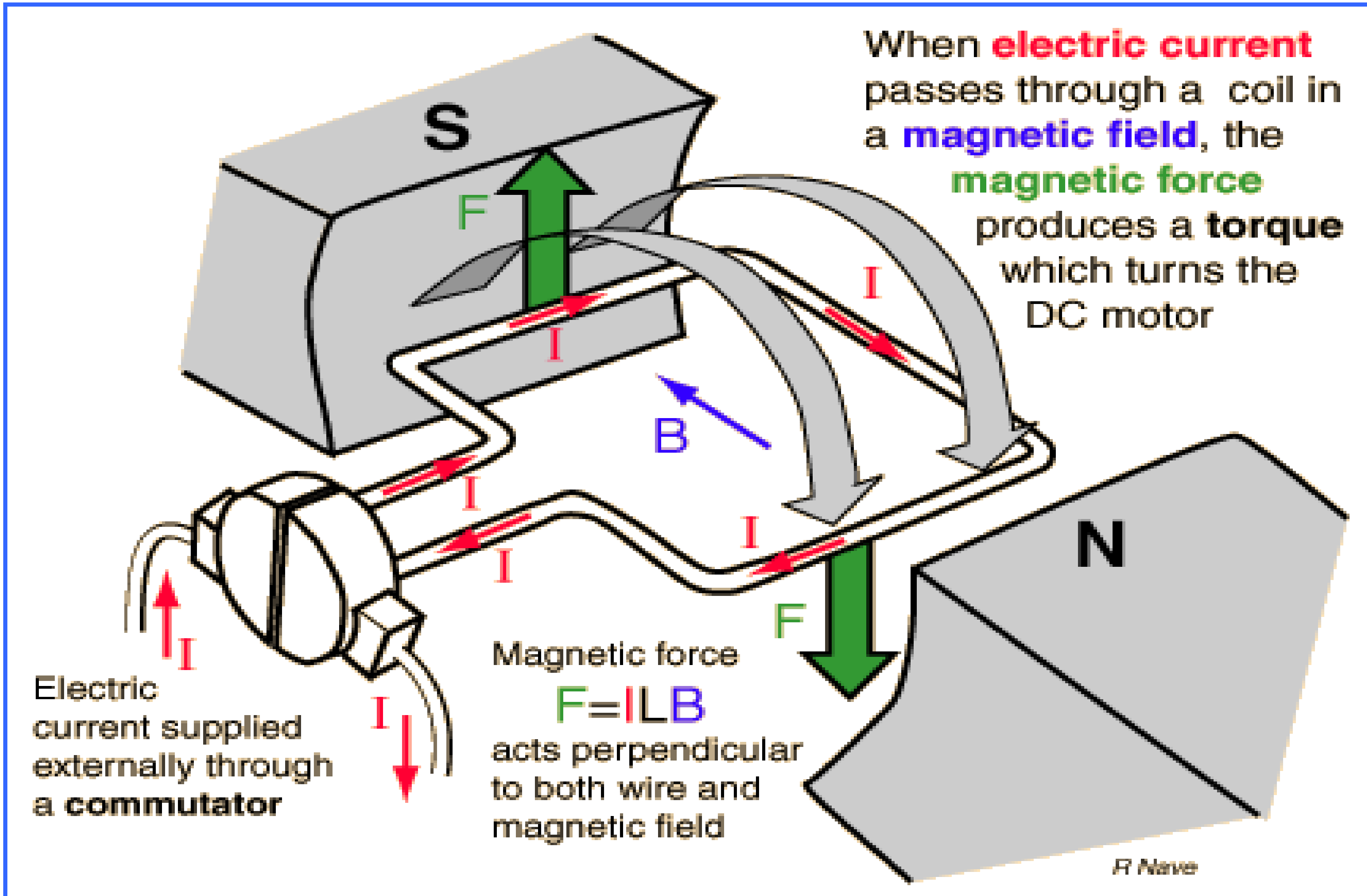
Commutator: It consist of large number of wedge-shaped copper segments Or bars, assembled side by side to form ring. The segments are insulated from one another by thin mica sheets. Each segment is connected to the coil end of armature winding. The communator is the part of the rotor and participates in its rotation.

Brushes: Two stationary brushes, made of carbon, are pressed against the commutator. The brush-commutator system provides two related functions

a. Electric connection is made with the moving rotor
b. Direct voltage is obtained from the alternating emf generated in the rotating conductor



WORKING OF DC MOTOR

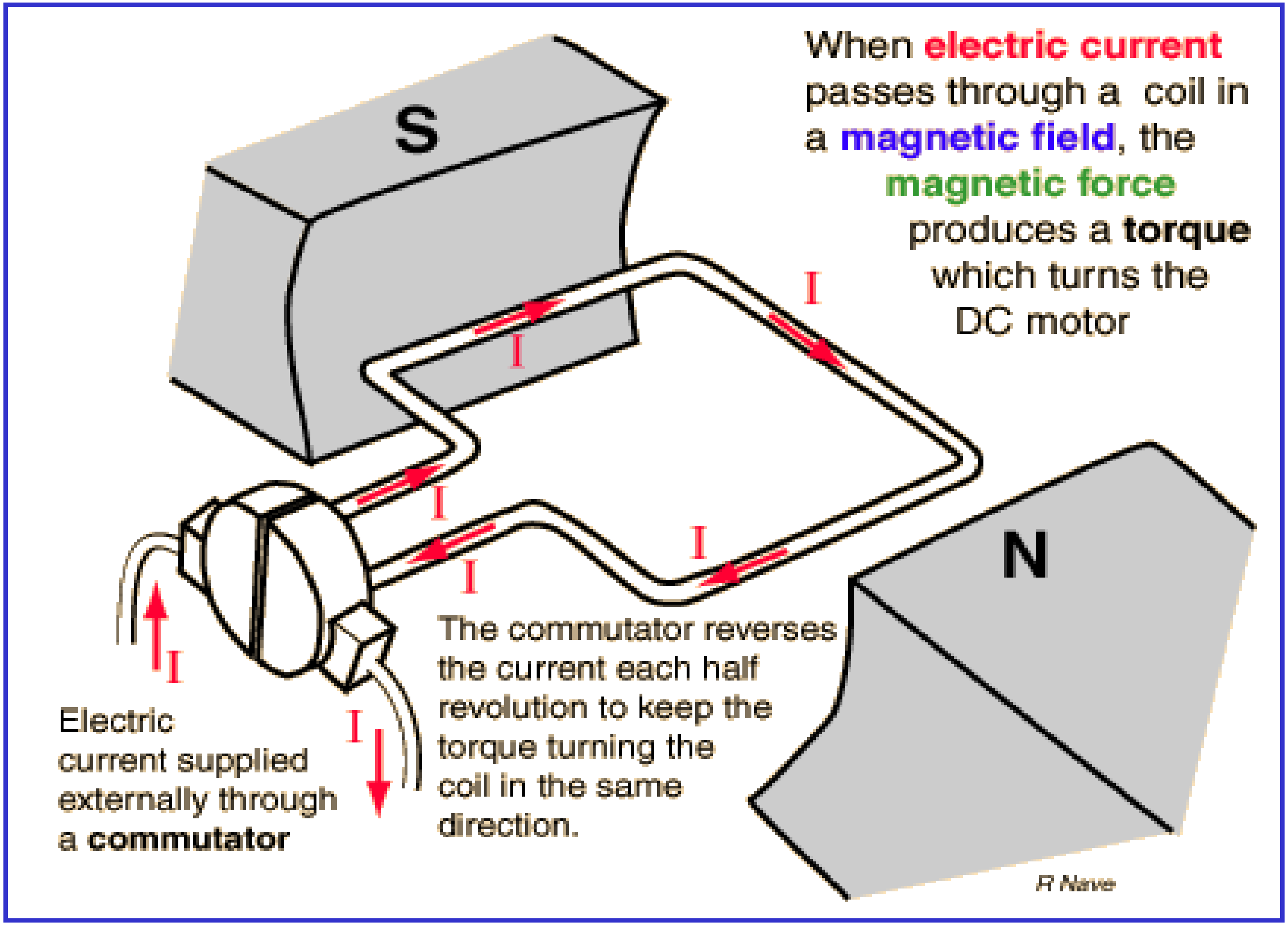


The force on a section of wire of length L carrying a current I through a magnetic field B is

- **An Electric DC motor is a machine which converts electric energy into mechanical energy. The working of DC motor is based on the principle that when a current-carrying conductor is placed in a magnetic field, it experiences a mechanical force.**

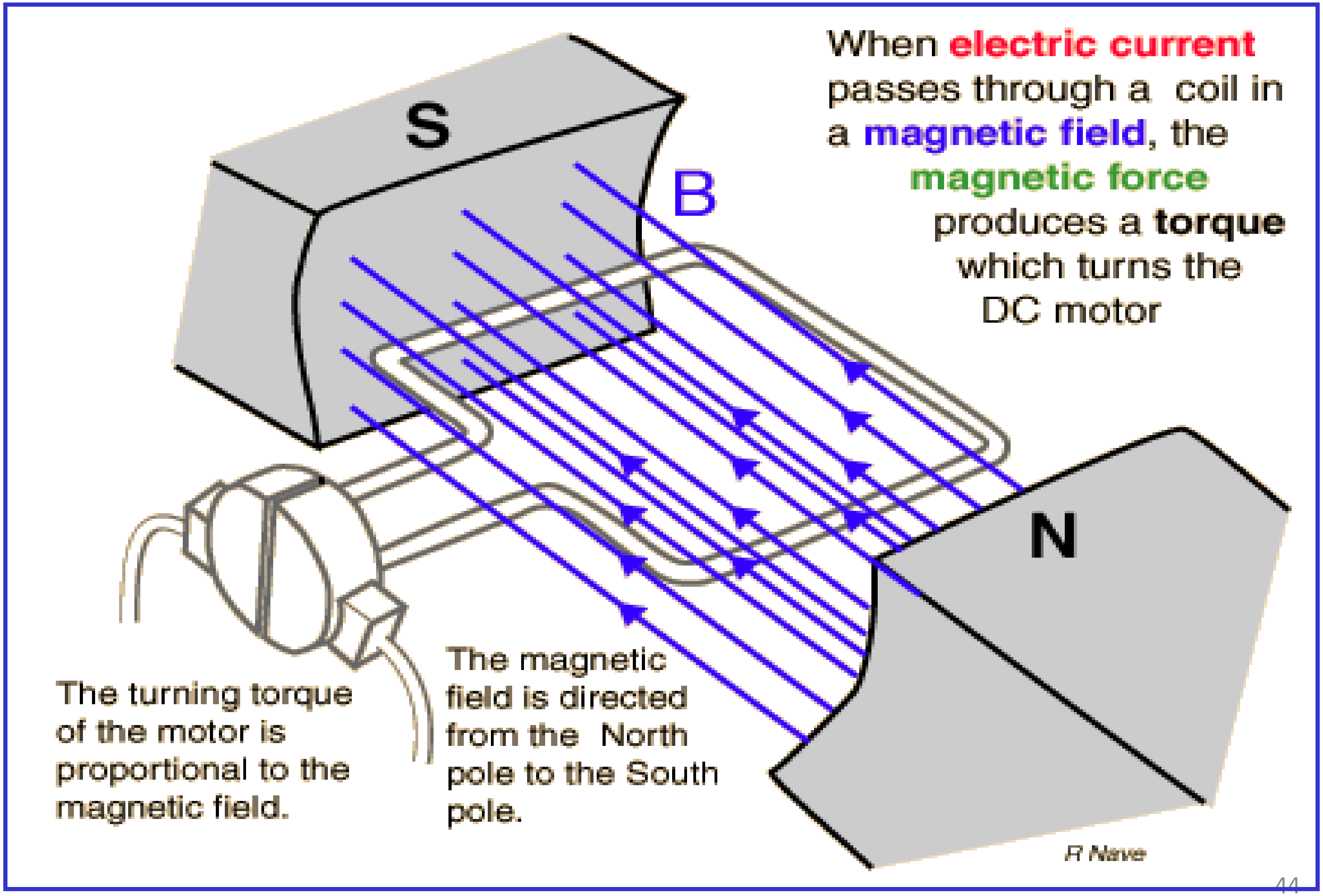
Torque is a measure of the force that can cause an object to rotate about an axis

Current in DC Motor

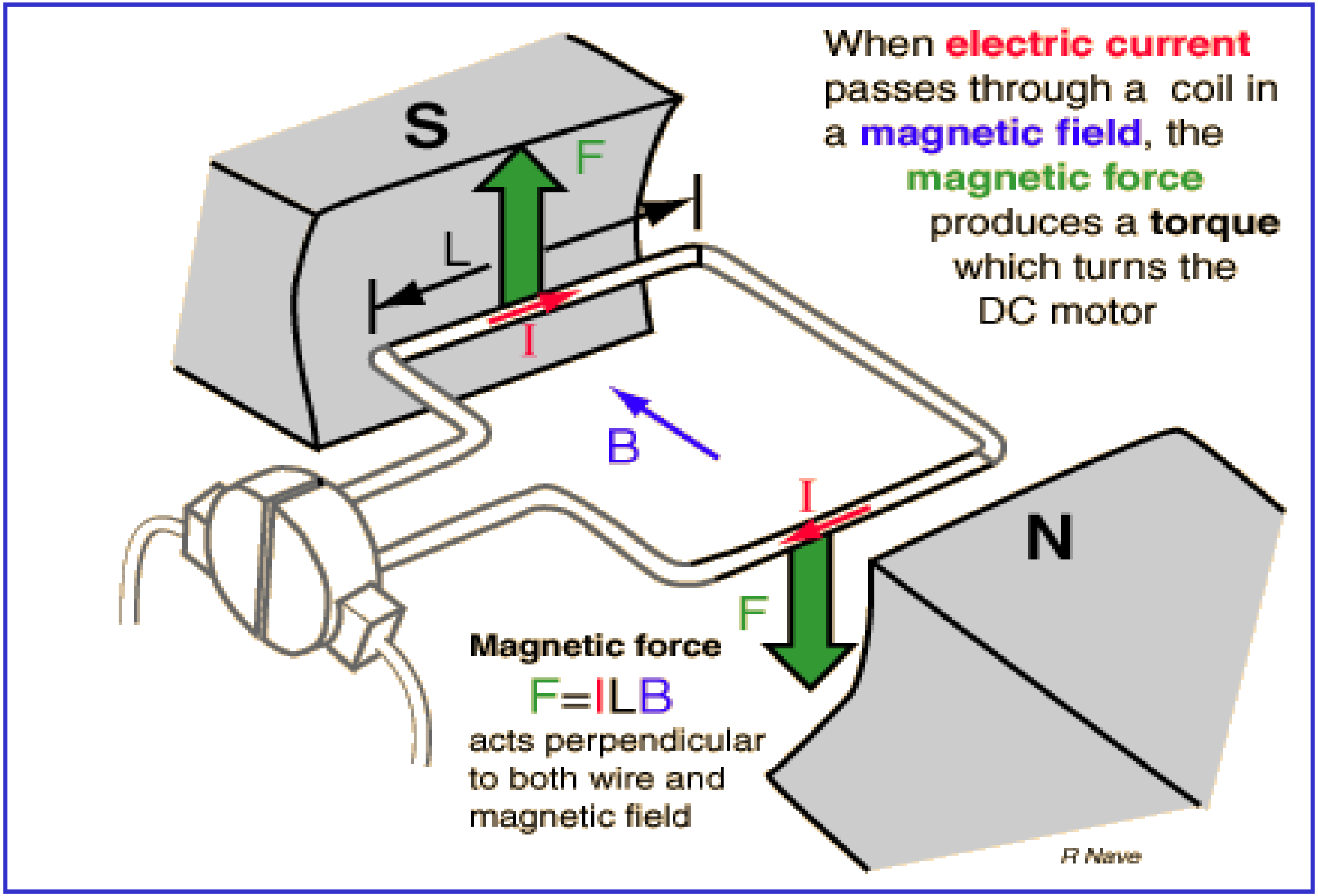


- On applying Fleming's left hand rule, it is clear that force on each conductor is tending to rotate the armature in anticlockwise direction. All these forces add together to produce a driving torque which sets the armature rotating.
  When the conductor moves from one side of a brush to the other, the current in that conductor is reversed and at the same time it comes under the influence of next pole which is of opposite polarity. Consequently, the direction of force on the conductor remains the same.

Magnetic Field in DC Motor



Force in DC Motor



summary