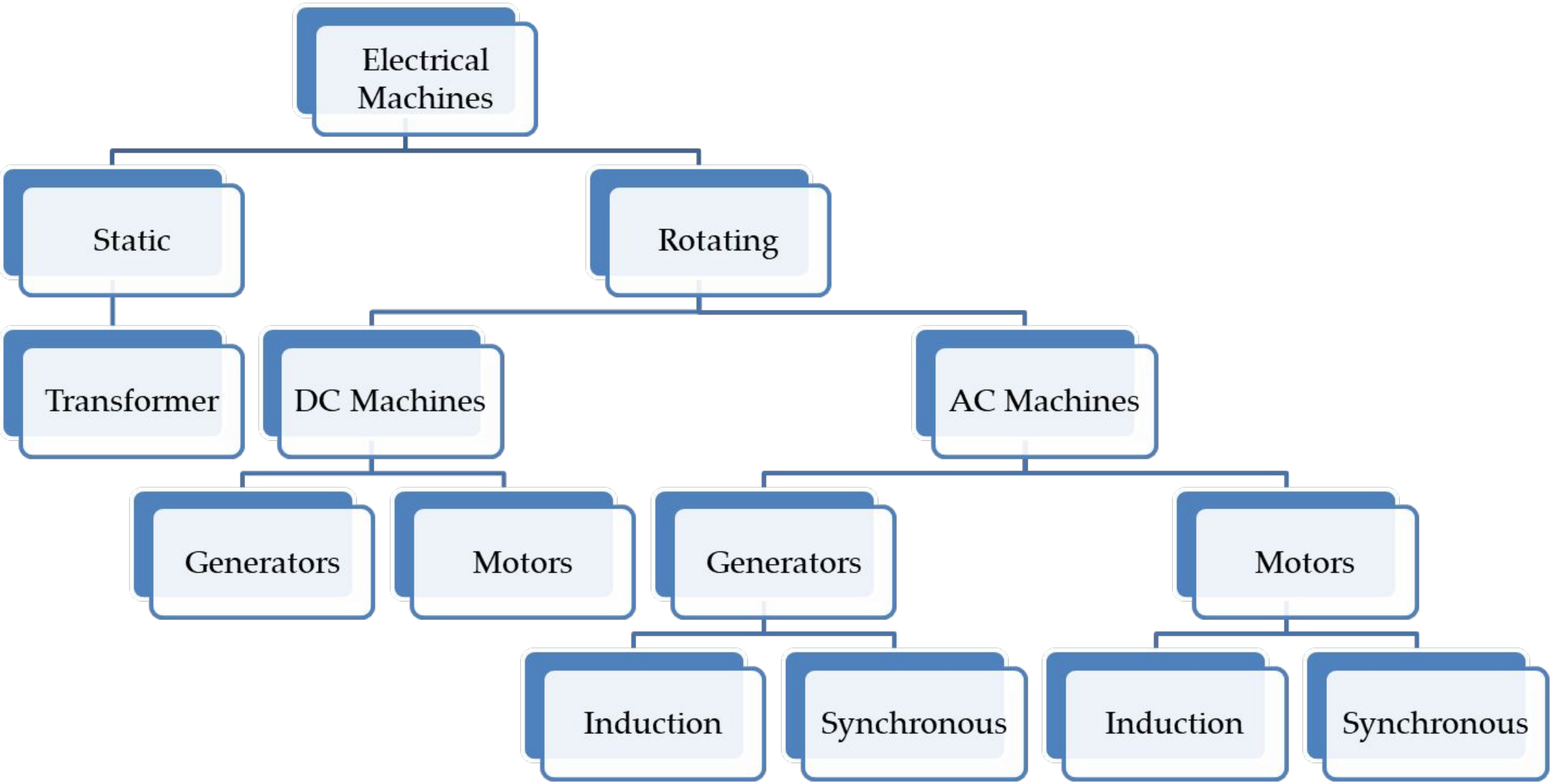
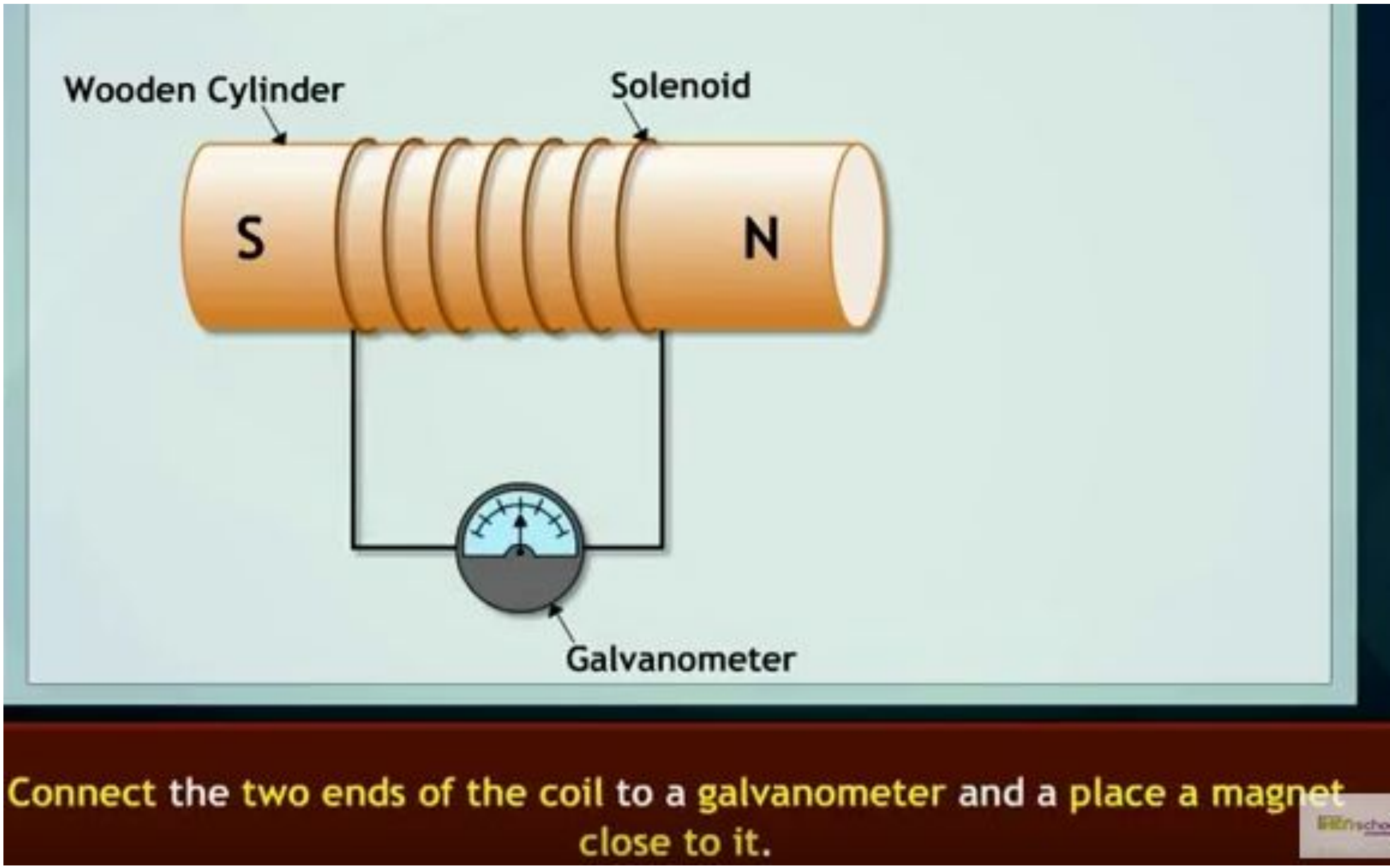
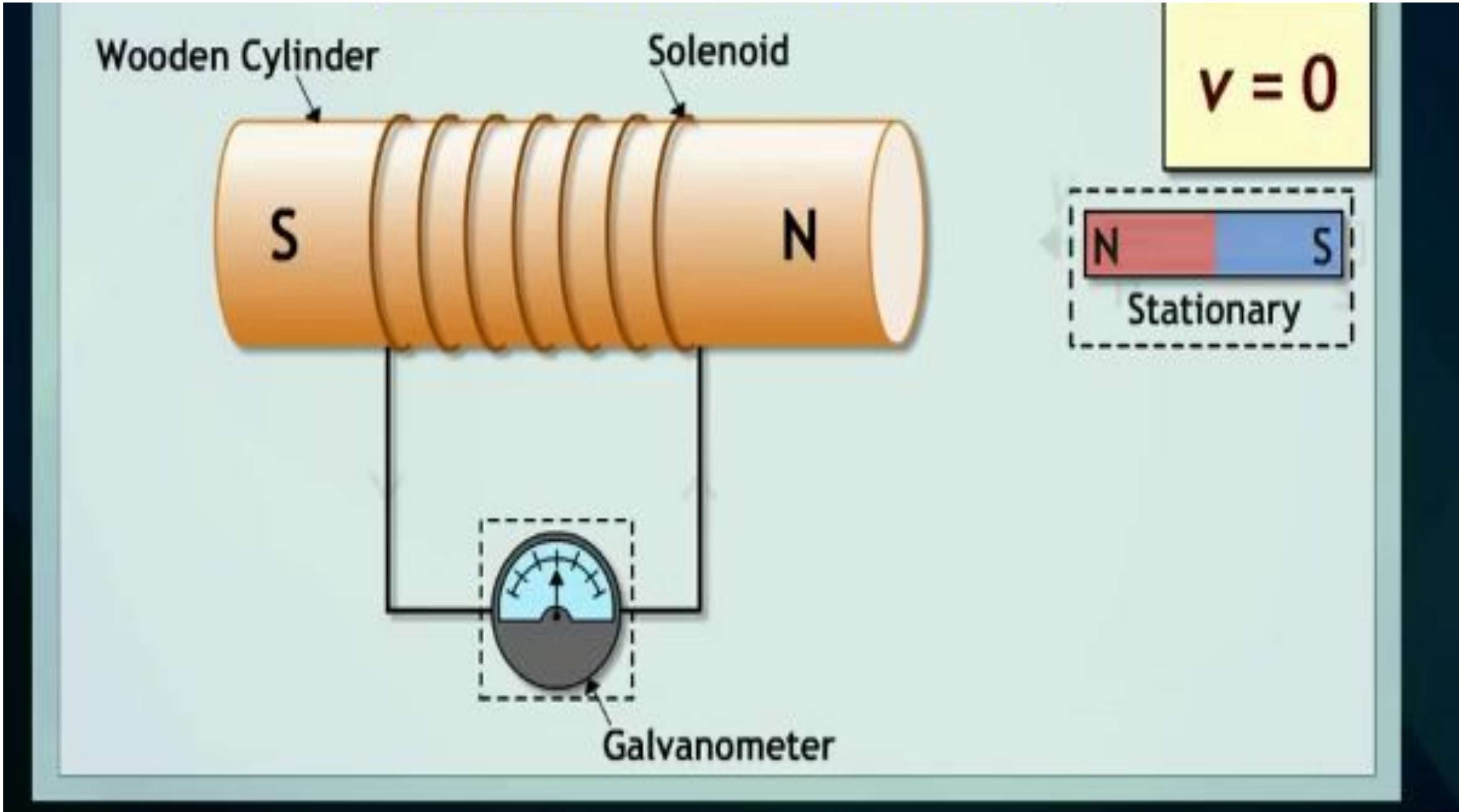
Construction Working principle of AC and DC machine


Electrical Machines
Static
Rotating
Transformer
DC Machines
AC Machines
Generators
Motors
Generators
Motors
Induction
Synchronous
Induction
Synchronous

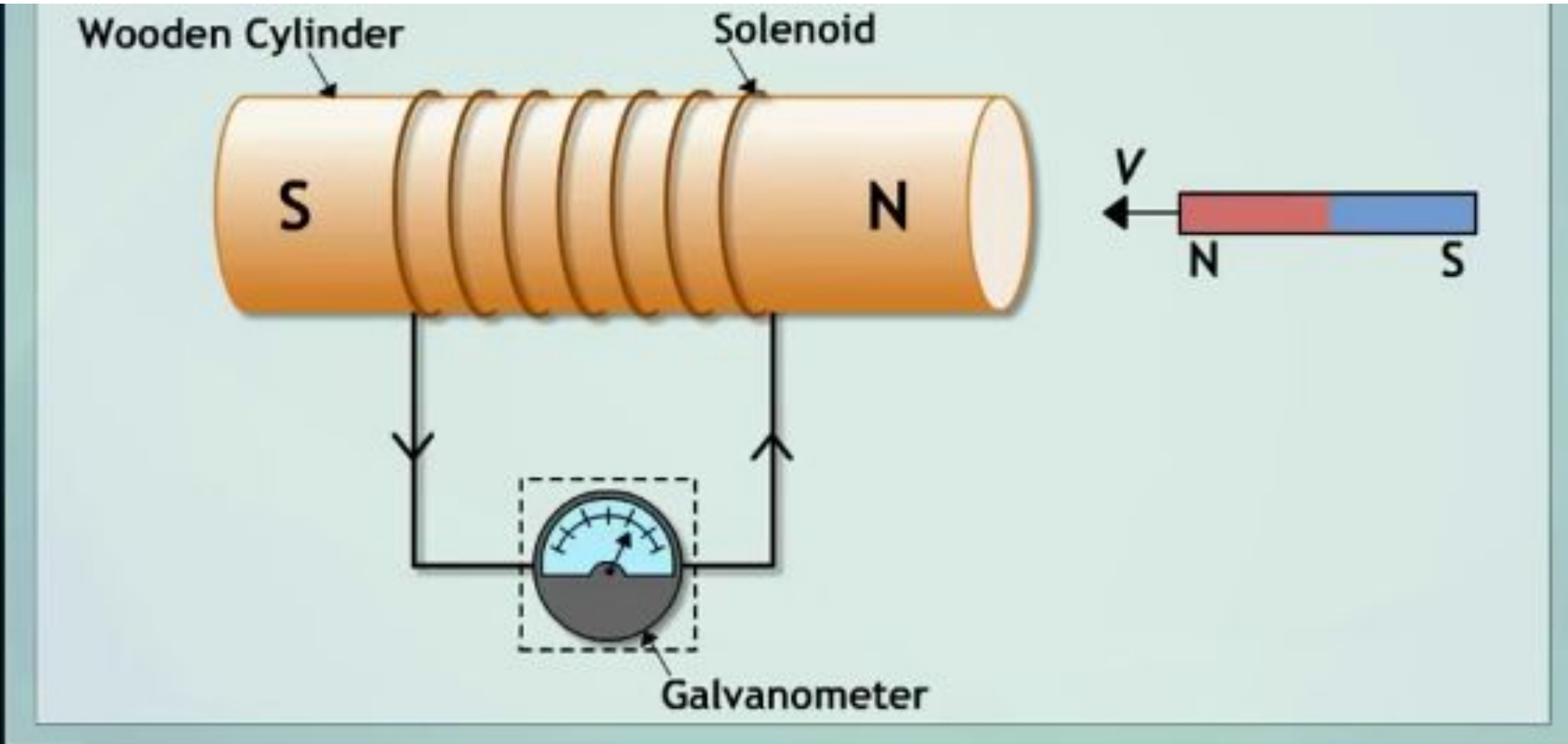
- ***Generators*** –
    - which convert mechanical energy into electrical energy

- ***MOTORS*** –
    - which convert electrical energy into mechanical energy

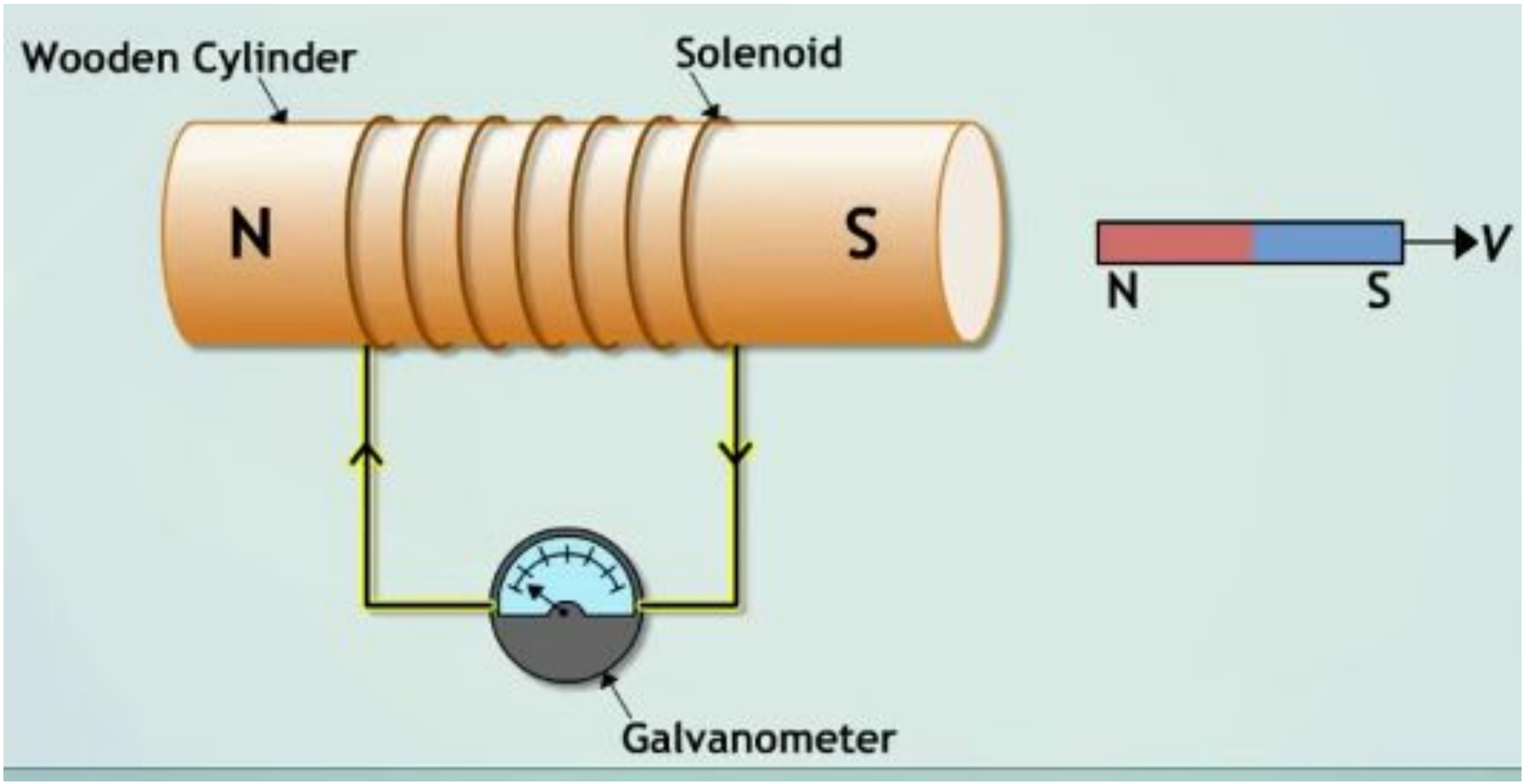

Wooden Cylinder
Solenoid
S
N
Galvanometer
Connect the two ends of the coil to a galvanometer and a place a magnet close to it.

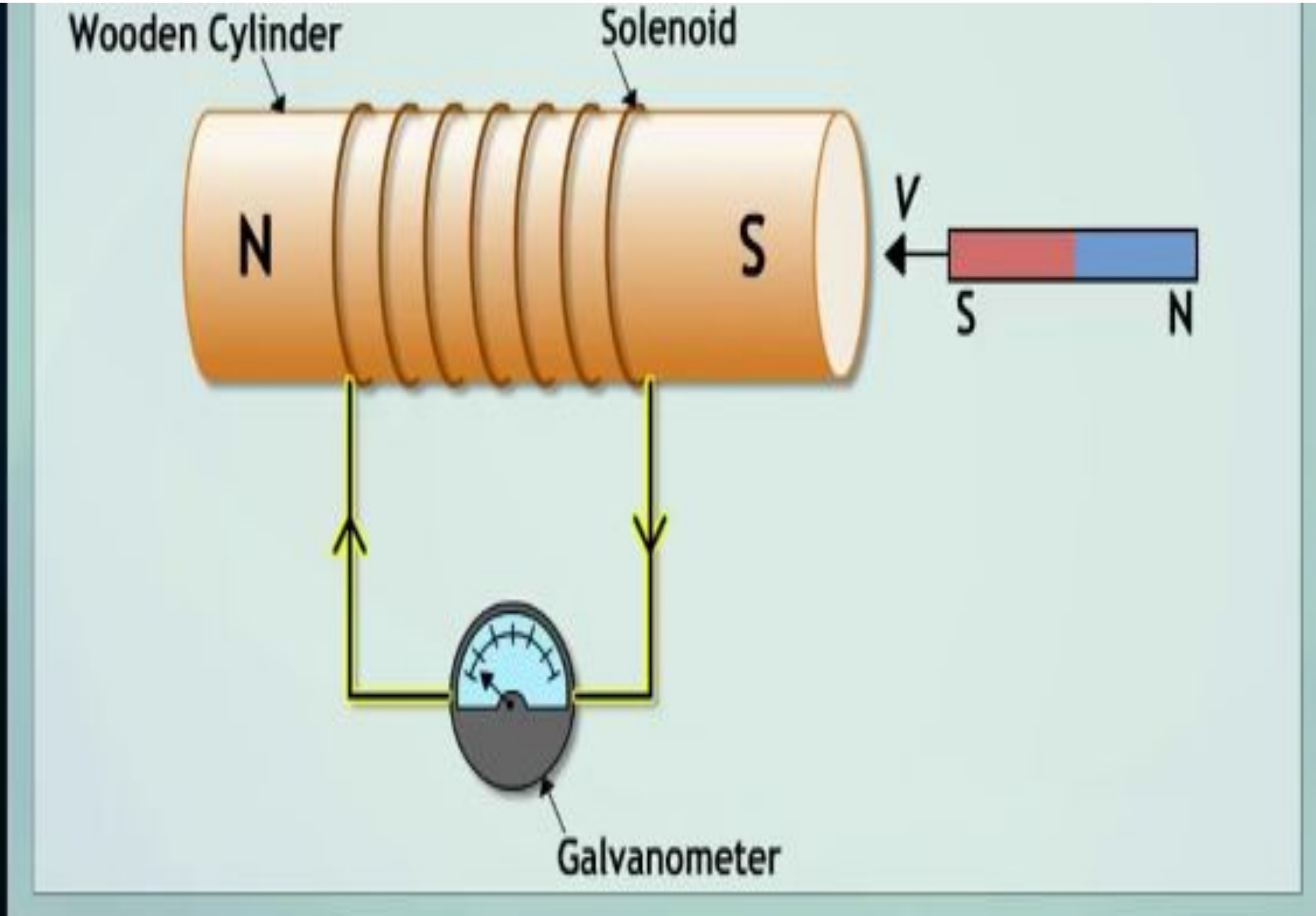


The reading of the galvanometer is zero when the magnet is stationary.

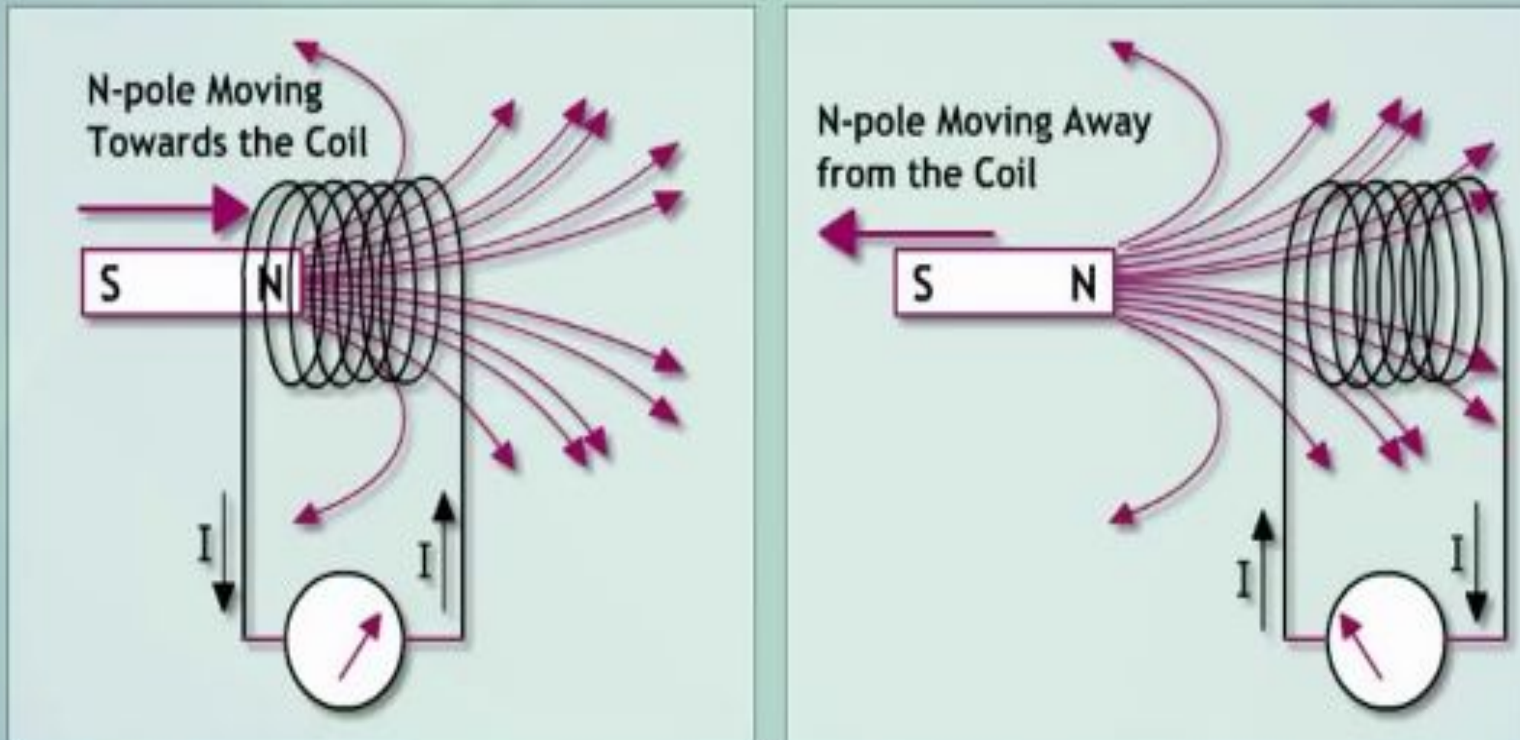


The pointer of the galvanometer deflects towards the right when the north pole of the magnet is moved towards the solenoid.


Wooden Cylinder
Solenoid
N
S
N
S
V
Galvanometer

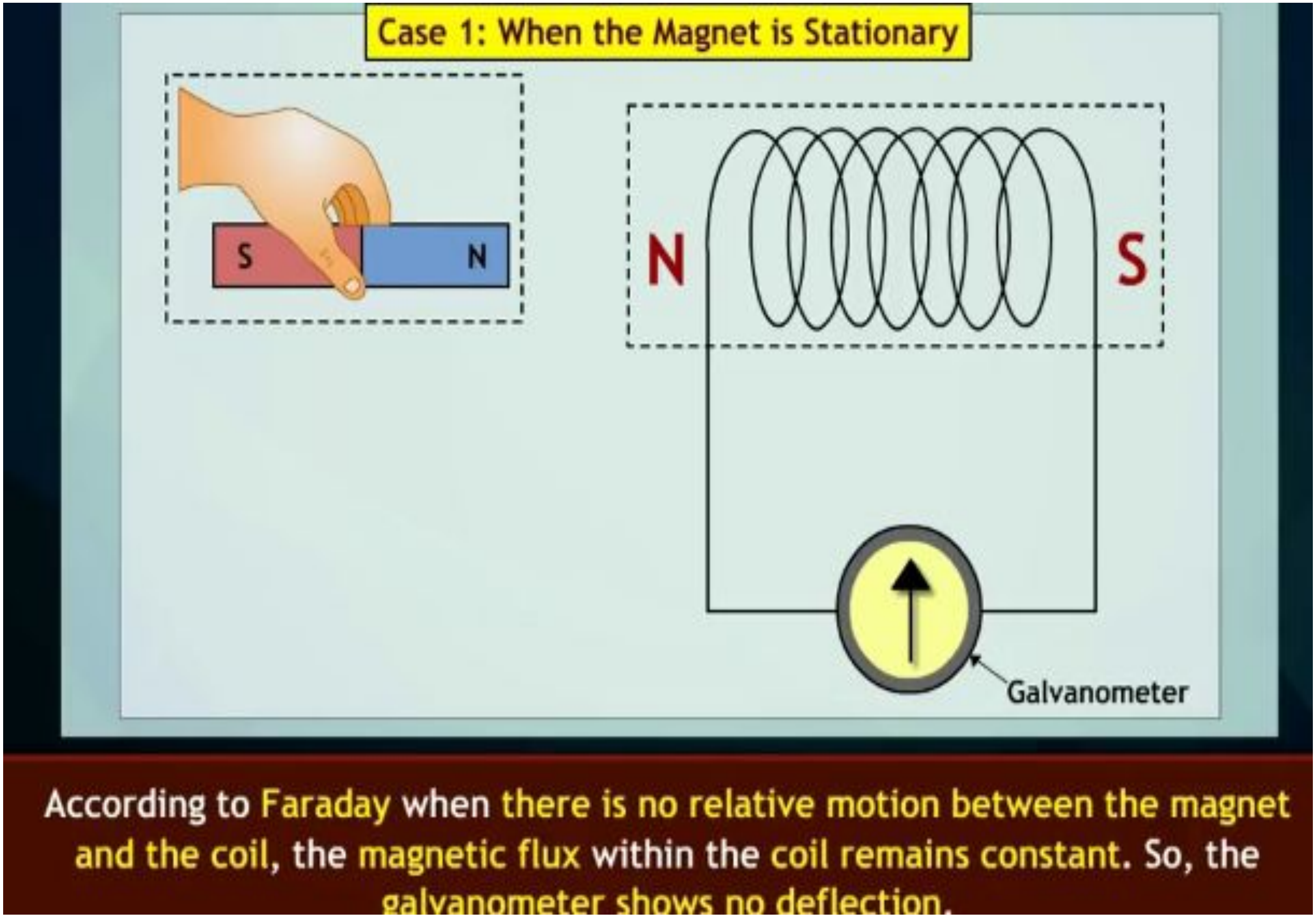


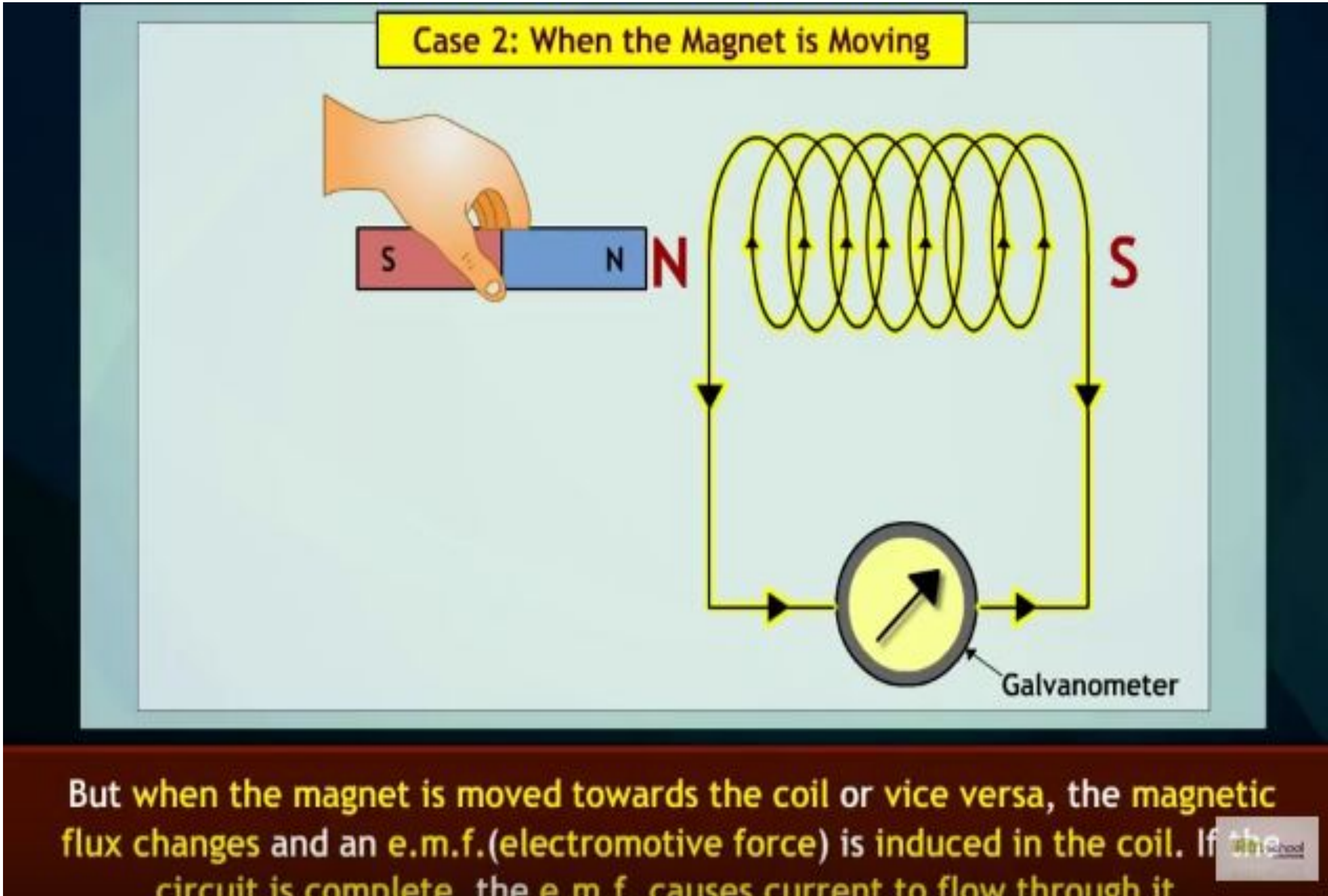
If the polarity of the magnet is reversed and the magnet is brought close to the solenoid, then current flows in an opposite direction. The galvanometer accordingly turns towards the left.

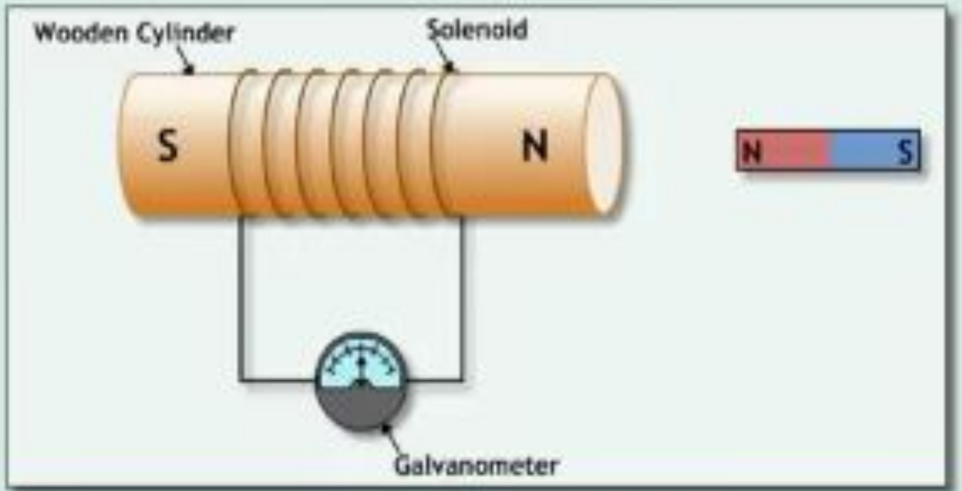


If the current is positive, for example, when the magnet is pushed toward the coil, it will be negative when the magnet is pulled away from the coil.

The direction of deflection in the galvanometer is reversed if the direction of motion is reversed.

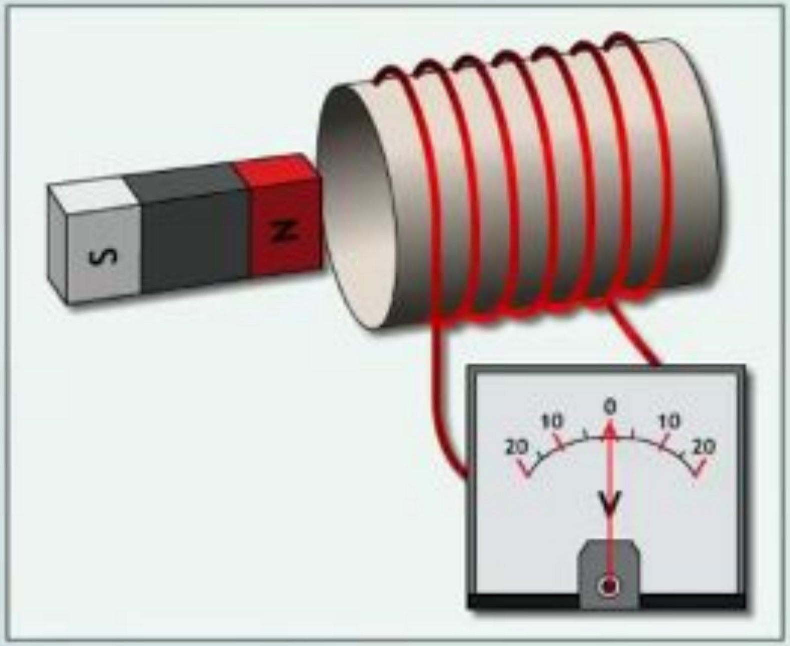

Case 1: When the Magnet is Stationary
S
N
N
S
Galvanometer
According to Faraday when there is no relative motion between the magnet and the coil, the magnetic flux within the coil remains constant. So, the galvanometer shows no deflection.


Case 2: When the Magnet is Moving
S
N
N
S
Galvanometer
But when the magnet is moved towards the coil or vice versa, the magnetic flux changes and an e.m.f.(electromotive force) is induced in the coil. If the circuit is complete, the e.m.f. causes current to flow through it.



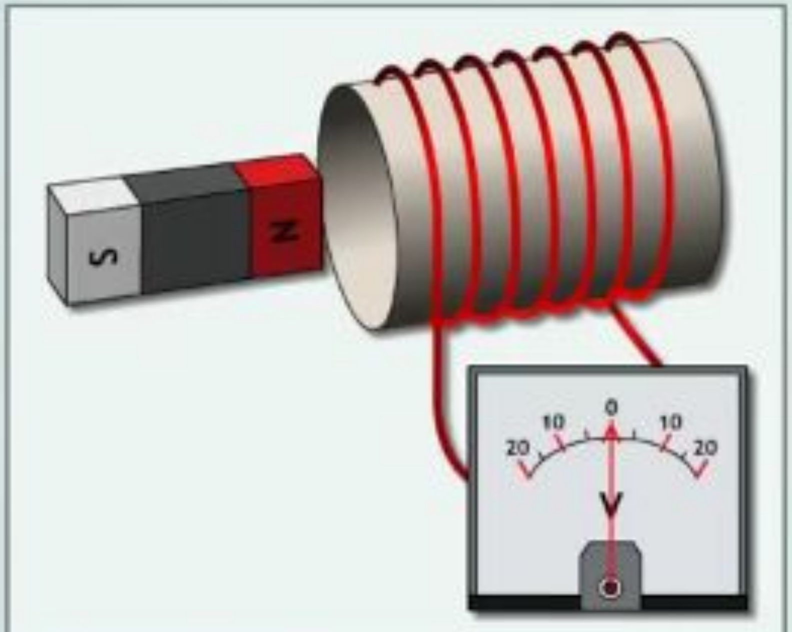
Position of Magnet	Deflection in Galvanometer
Magnet at rest	No deflection in galvanometer
Magnet moves towards the coil	Deflection in galvanometer in one direction
Magnet is held stationary at same position (near the coil)	No deflection in galvanometer
Magnet moves away from the coil	Deflection in galvanometer but in opposite direction
Mgnet is held stationary at same position (away from the coil)	No deflection in galvanometer

Faraday's Law of Induction



Whenever there is a change in the magnetic flux linked with a coil, an electromotive force (e.m.f.) is induced.

Faraday's Law of Induction

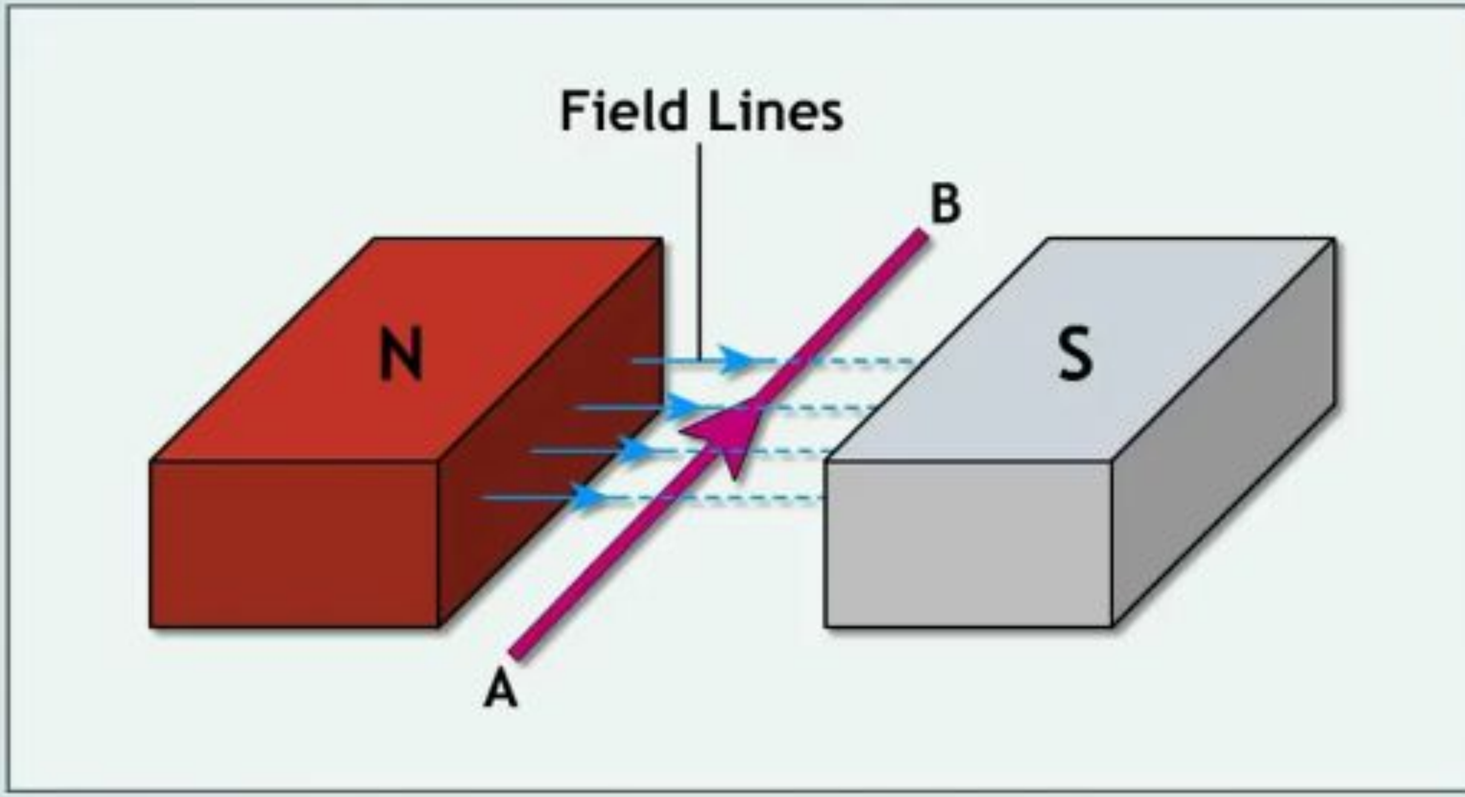


Factors affecting the Magnitude of the e.m.f.

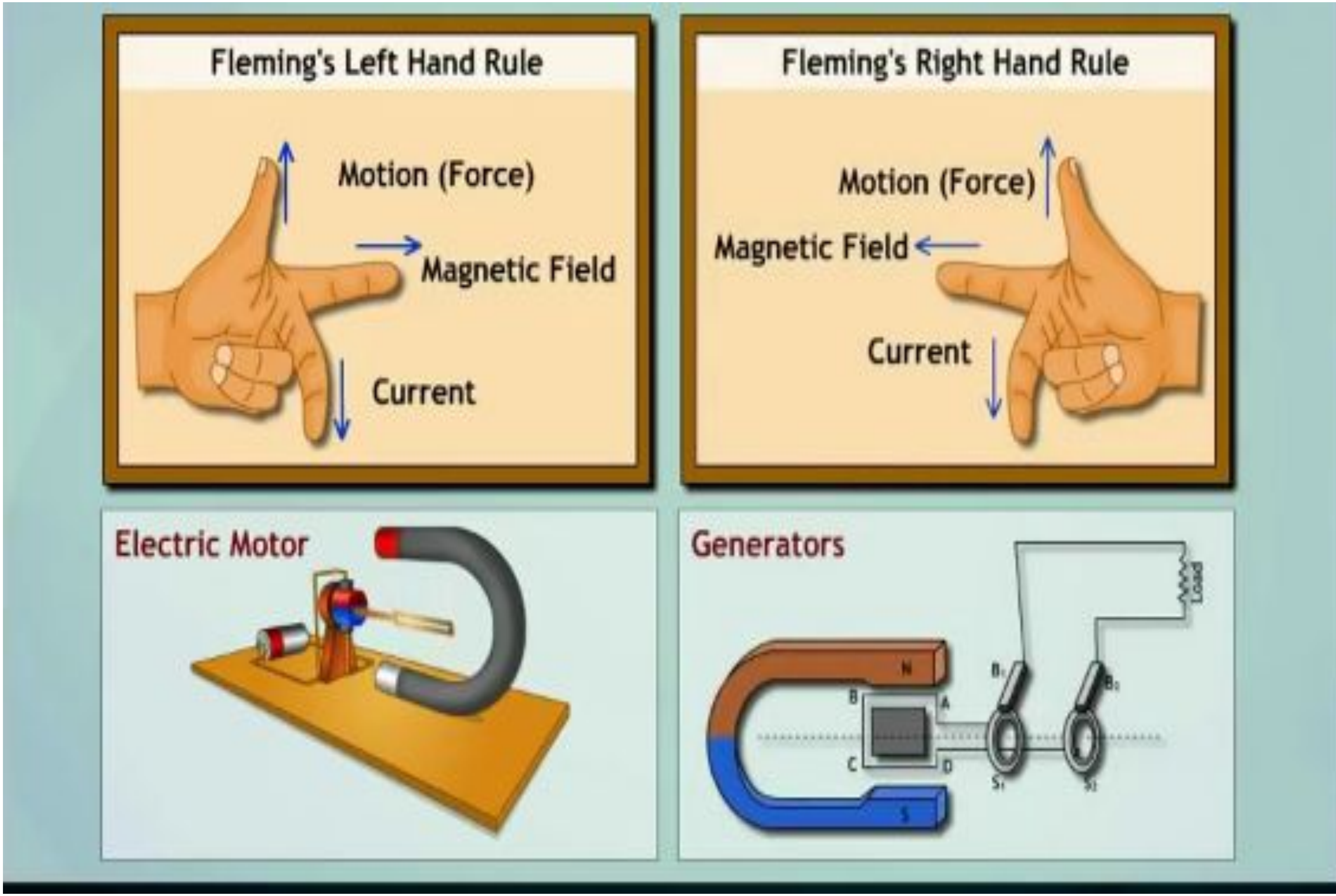
(i) Change in Magnetic Flux

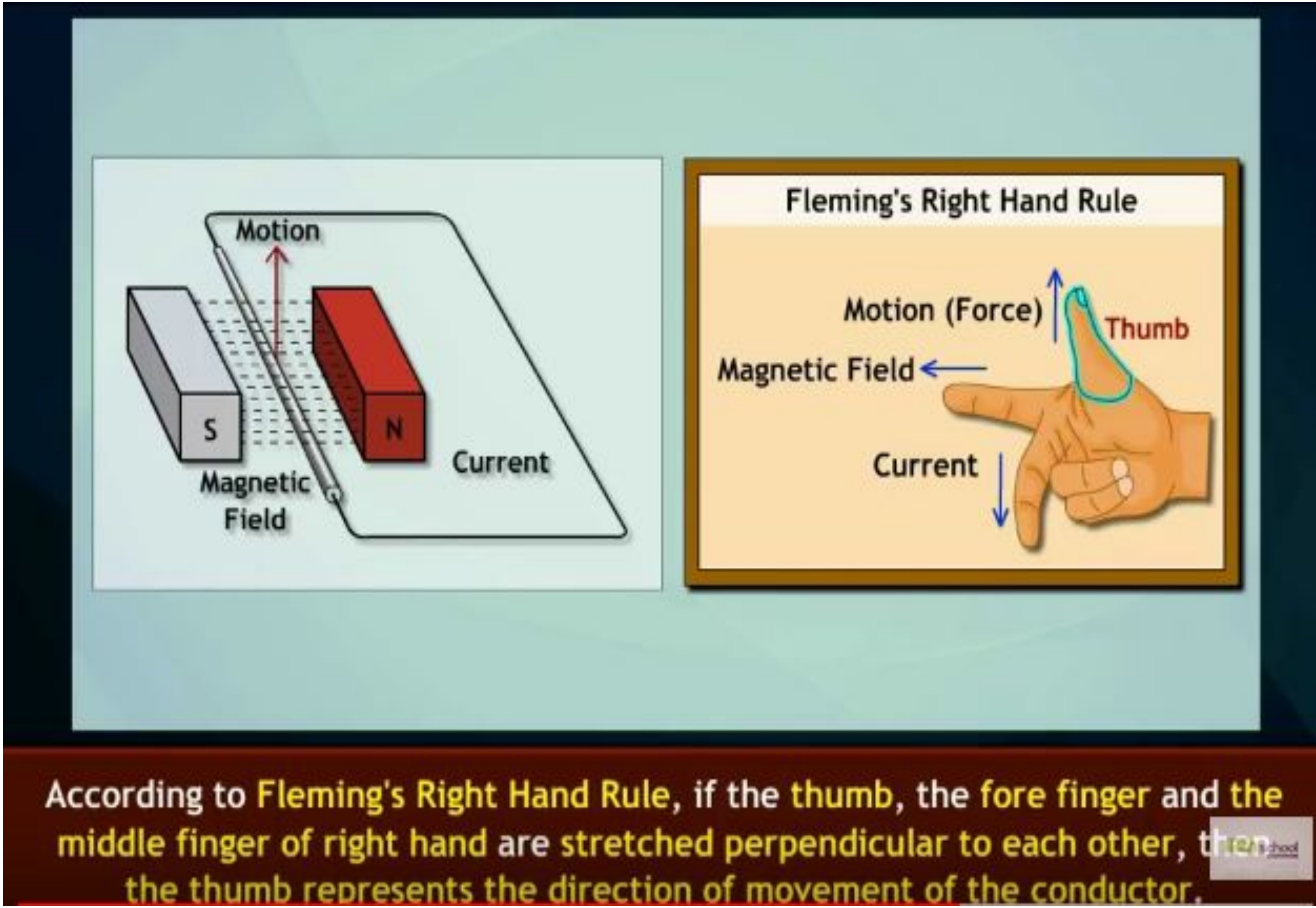
(ii) Time in which the Flux changes

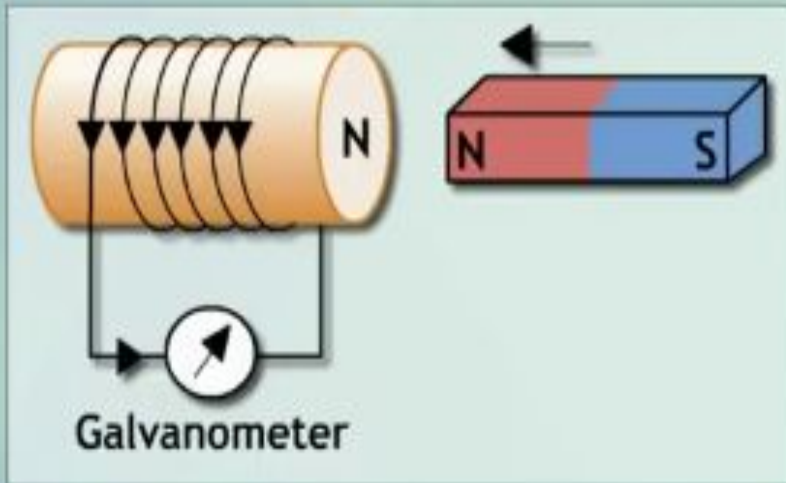
The magnitude of the induced e.m.f. is directly proportional to the rate of change of the magnetic flux linked with the coil.

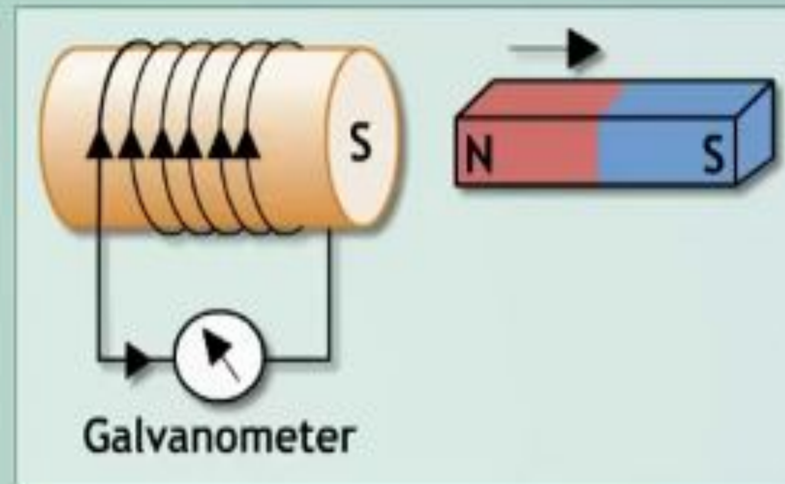


The direction of the induced e.m.f. depends on whether there is an increase or decrease in the magnetic flux.


Fleming's Left Hand Rule
Motion (Force)
Magnetic Field
Current
Fleming's Right Hand Rule
Motion (Force)
Magnetic Field
Current
Electric Motor
Generators
N
S
A
B
C
D


Motion
S
N
Magnetic
Field
Current
Fleming's Right Hand Rule
Motion (Force)
Thumb
Magnetic Field
Current
According to Fleming's Right Hand Rule, if the thumb, the fore finger and the middle finger of right hand are stretched perpendicular to each other, then
the thumb represents the direction of movement of the conductor.



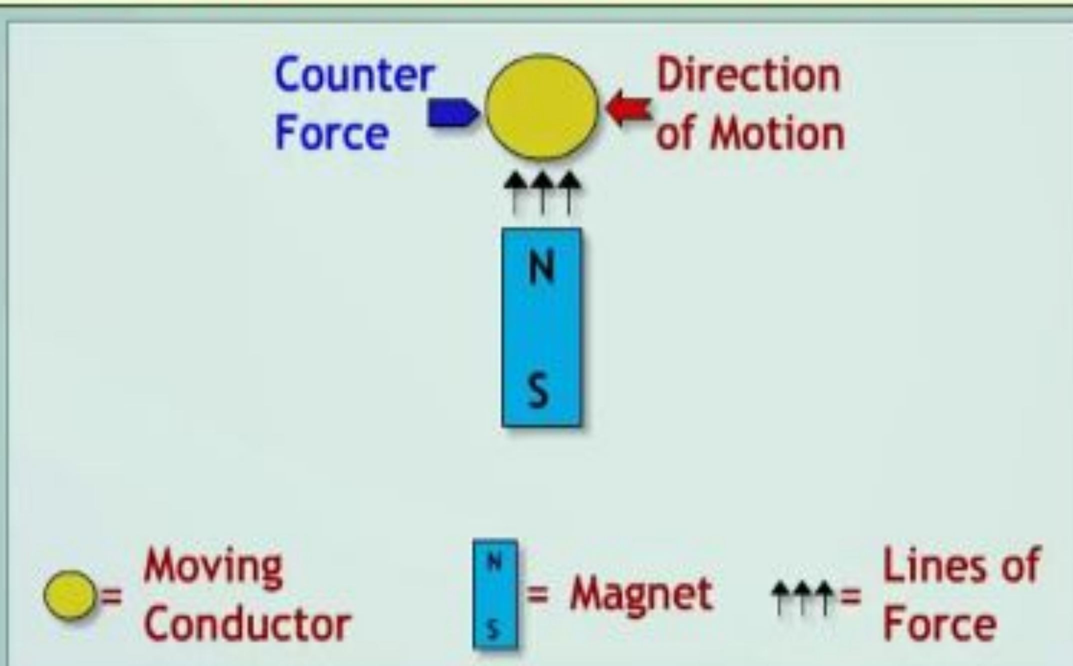


By Lenz's Law, when magnet is inserted into the solenoid, a North pole will be induced on the right side of coil to oppose the incoming North pole.
By Right Hand Grip Rule, the induced current will flow anticlockwise so that pointer deflects to right.

By Lenz's Law, when magnet is withdrawn from the solenoid, a South pole will be induced on the right side of coil to oppose the outgoing North pole. By Right Hand Grip Rule. the induced current will flow clockwise so that pointer deflects to left.

Lenz's law states that the direction of the induced e.m.f. is such that it always tends to oppose the cause which produces it.

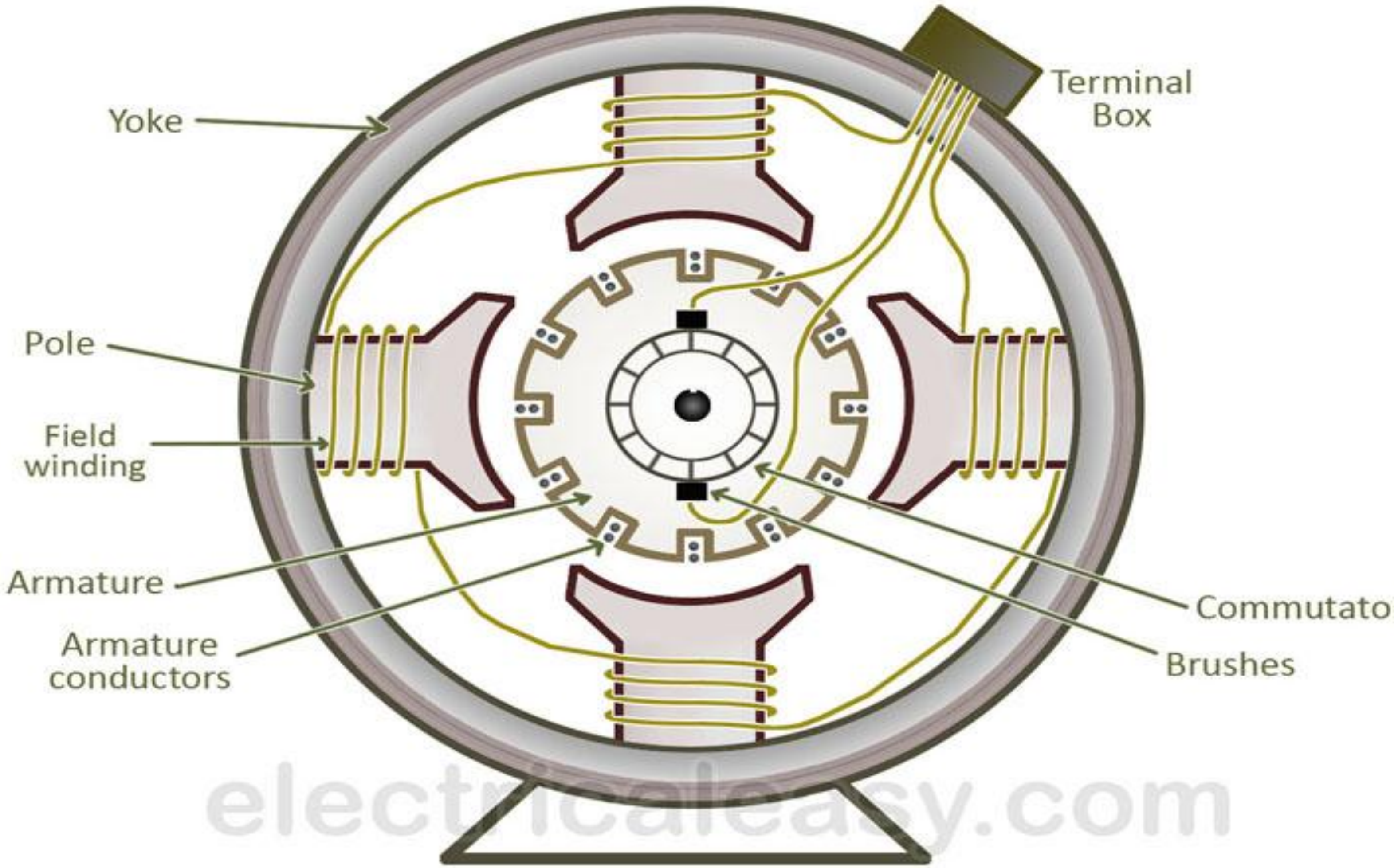
More counter force is developed when the speed of the conductor, magnetic force, conductor size or conductor conductivity increases



Lenz's law obeys Newton's Third Law of Motion which states that to every action there is always an equal and opposite reaction.

– This energy conversion is based on the principle of production of ***dynamically induced emf.***

- ***Construction of a DC Machine*:**



- The DC Generators and DC Motors have the **Same General Construction.**
- In fact, when the machine is being assembled, the **workmen usually do not know whether** it is a DC Generator or Motor.
- Any DC Generator can be run as a DC Motor and vice-versa.

- A DC machine consists two basic parts:
  - Stator
  - Rotor

Constructional Parts

1. Yoke
2. Poles and pole shoes
3. Field winding
4. Armature core
5. Armature winding
6. Commutator and brushes

- ***Yoke:***
  - The outer frame of a dc machine is called as yoke.
  - It is made up of cast iron or steel.
  - It not only provides mechanical strength to the whole assembly but also carries the magnetic flux produced by the field winding

- ***Poles and pole shoes***:
  - *Poles are joined to the yoke with the help of bolts or welding.*
  - They ***carry field winding*** and pole shoes are fastened to them.

Pole shoes serve two purposes;

- (i) They support field coils
  (ii) Spread out the flux in air gap uniformly

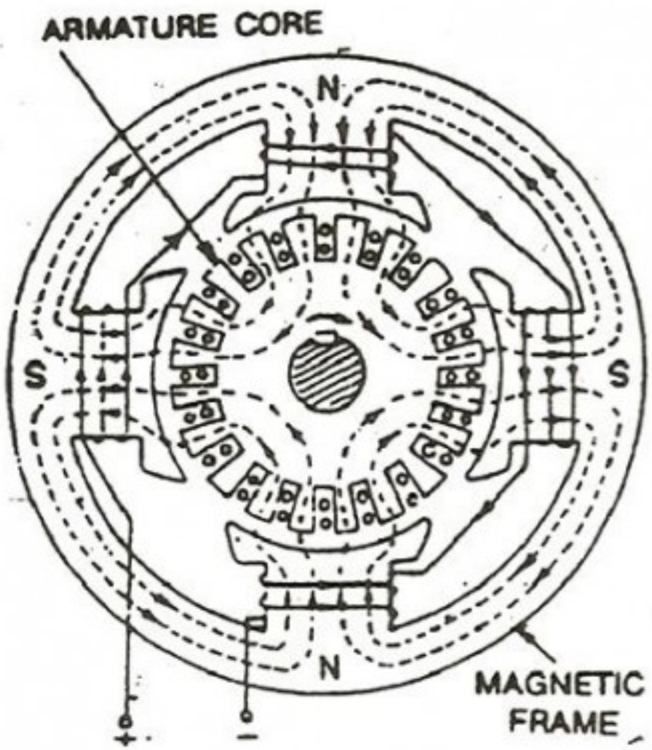
Field winding:

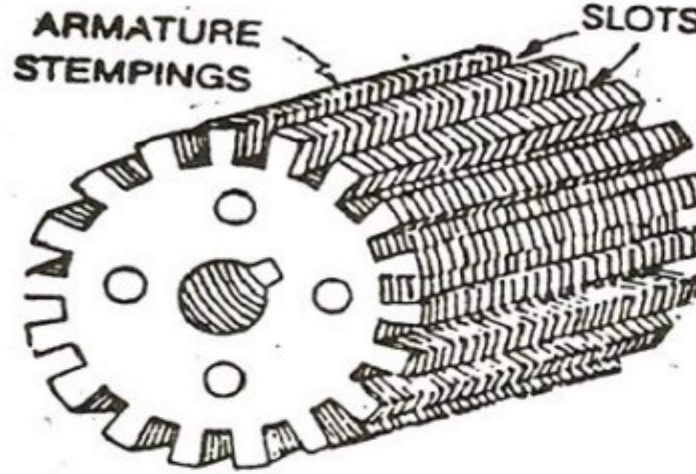
- They are usually made of copper.
- Field coils are former wound and placed on each pole and are connected in series.
- They are wound in such a way that, when energized, they form alternate North and South poles

- **Armature core:**
  - Armature core is the *rotor of the machine.*
  - It is *cylindrical in shape* with slots to carry armature winding.
  - The armature is built up of **thin (about 0.4 to 0.6 mm thick) laminated circular steel disks for *reducing eddy current losses.***

- It may be provided with air ducts for the axial air flow for cooling purposes. **Armature is keyed to the shaft**
- Practical D.C machines have air gaps ranging from 0.5 mm to 1.5 mm.

Armature Core

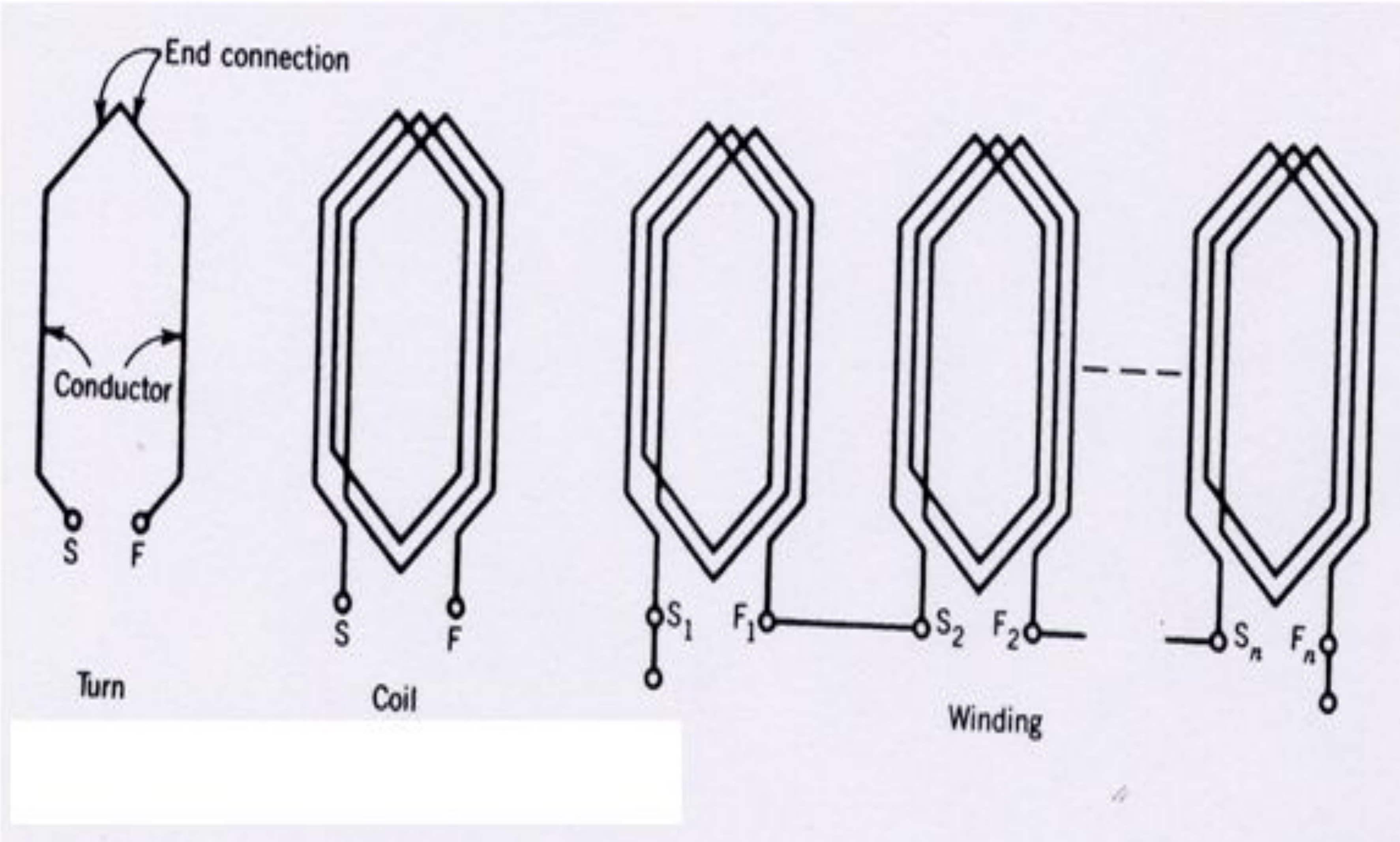

ARMATURE CORE
N
S
S
N
MAGNETIC
FRAME
+
−


ARMATURE
STEMPINGS
SLOTS

- **Armature winding**:
  - It is usually a former *wound copper coil* which rests in armature slots.
  - The armature conductors are insulated from each other and also from the armature core.
  - Armature winding can be wound by one of the two methods;
  - **lap winding**

    (OR)
  - **wave winding**.
  - Double layer lap or wave windings are generally used.
  - A double layer winding means that each armature slot will carry two different coils.

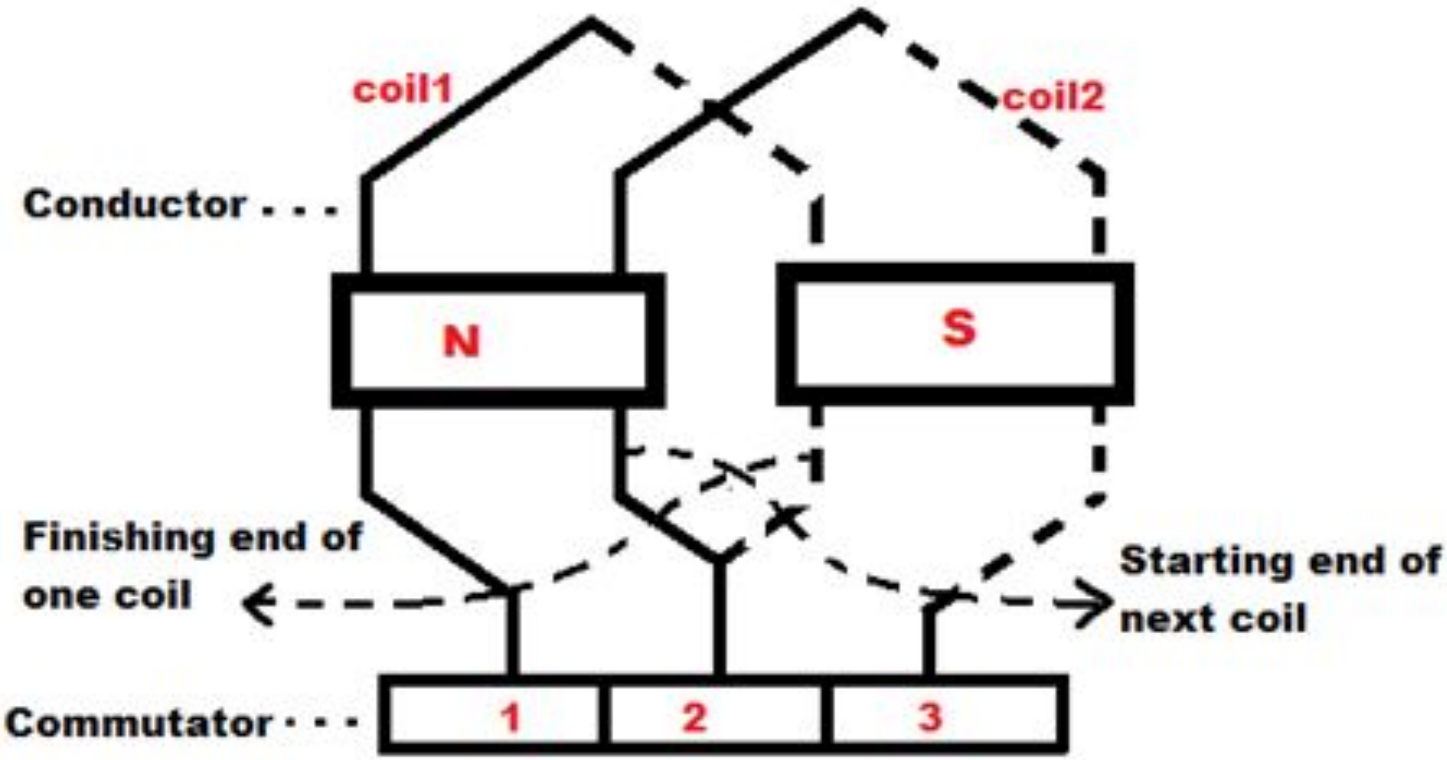
Armature Winding in a DC Machine



Lap Winding

Used in high current low voltage circuits

Number of parallel paths equals number of brushes or poles

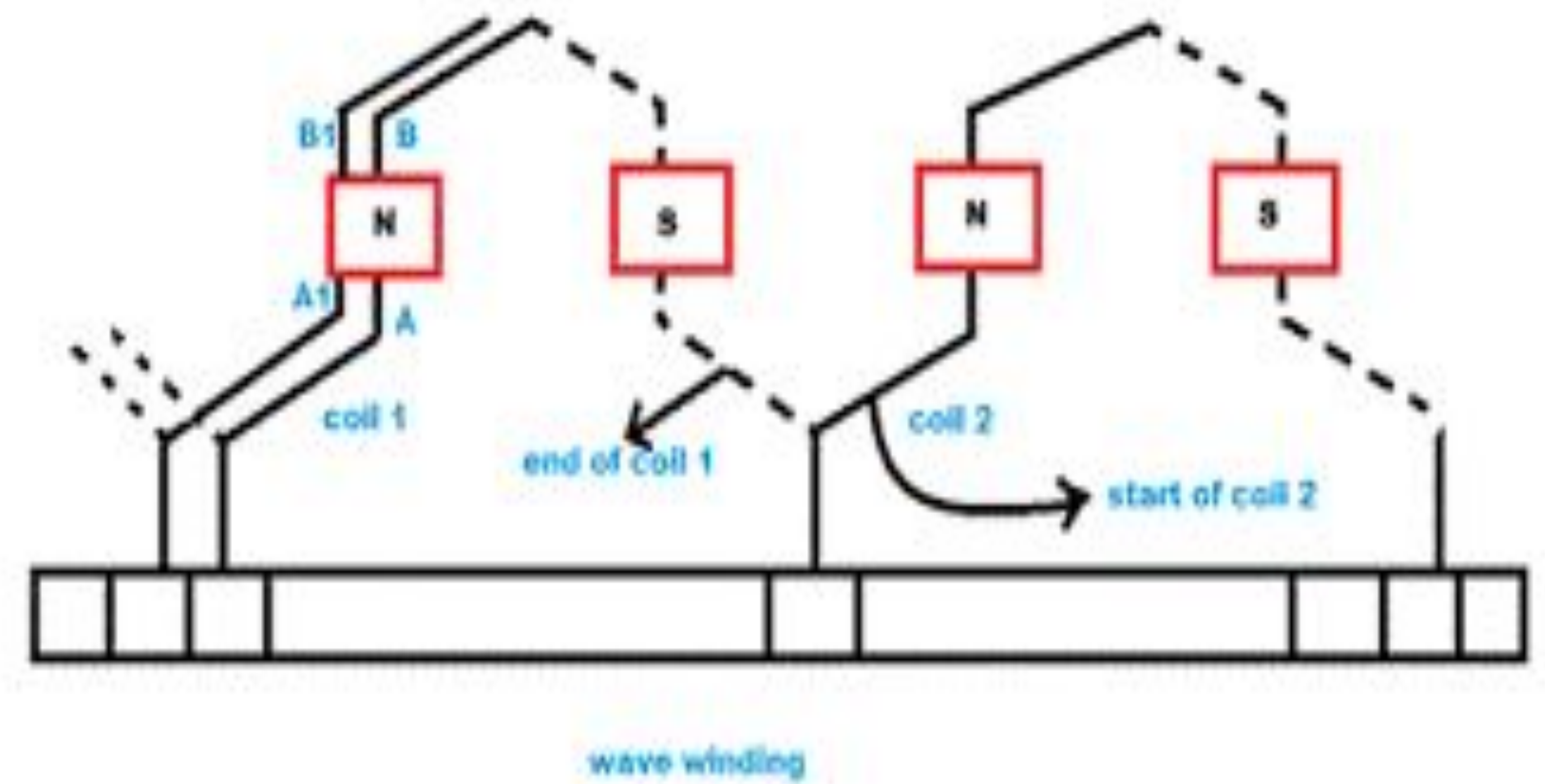


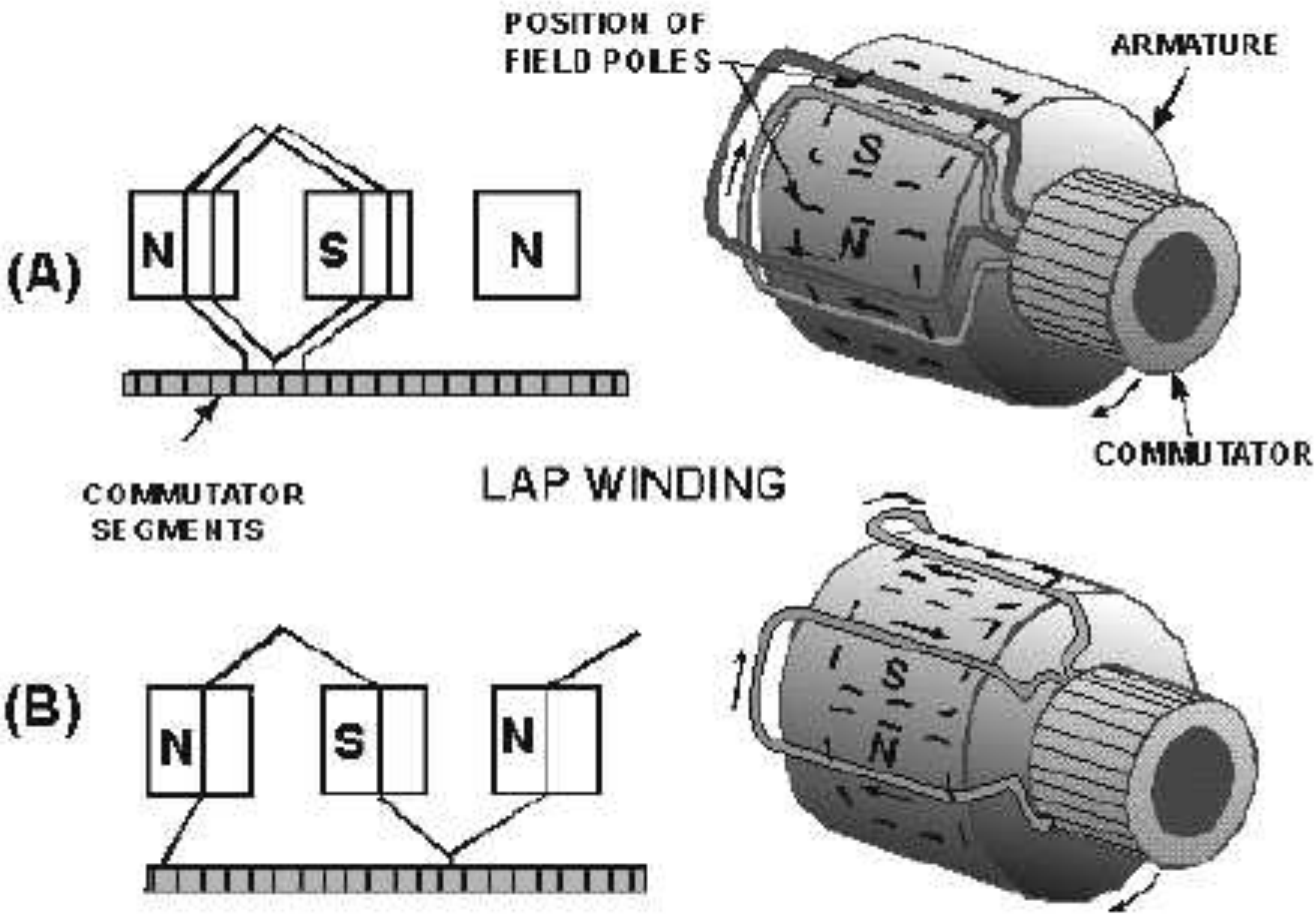
LAP winding

Wave Winding

Used in high voltage low current circuits

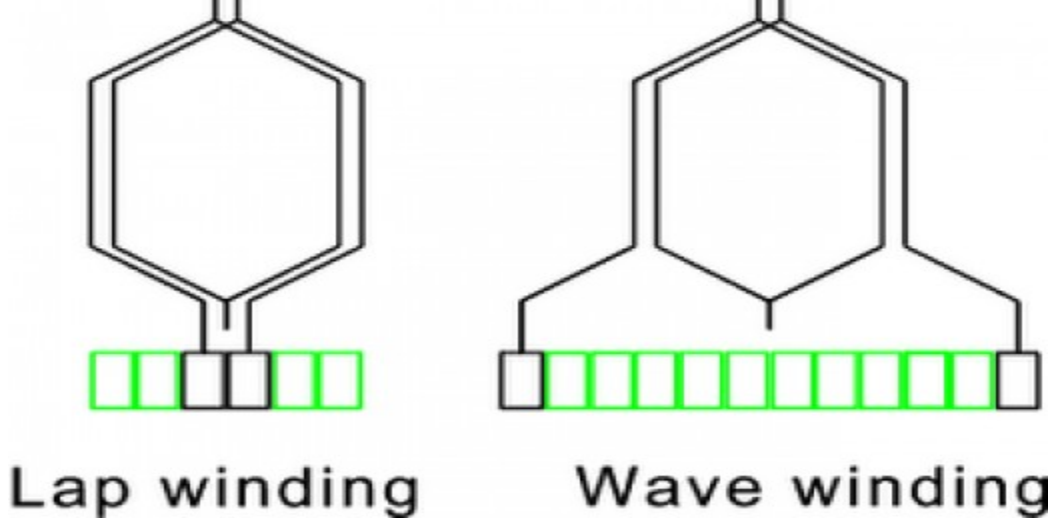
Number of parallel paths always equals 2

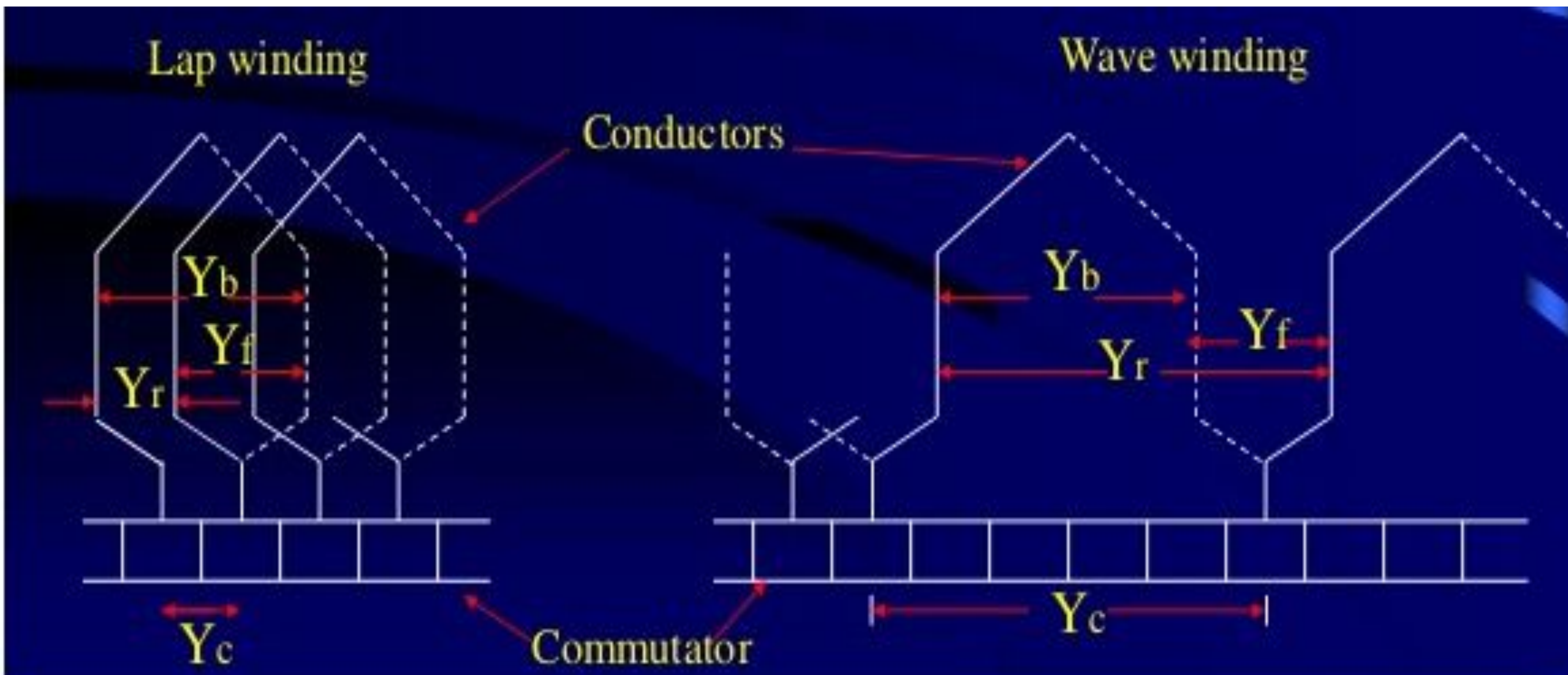




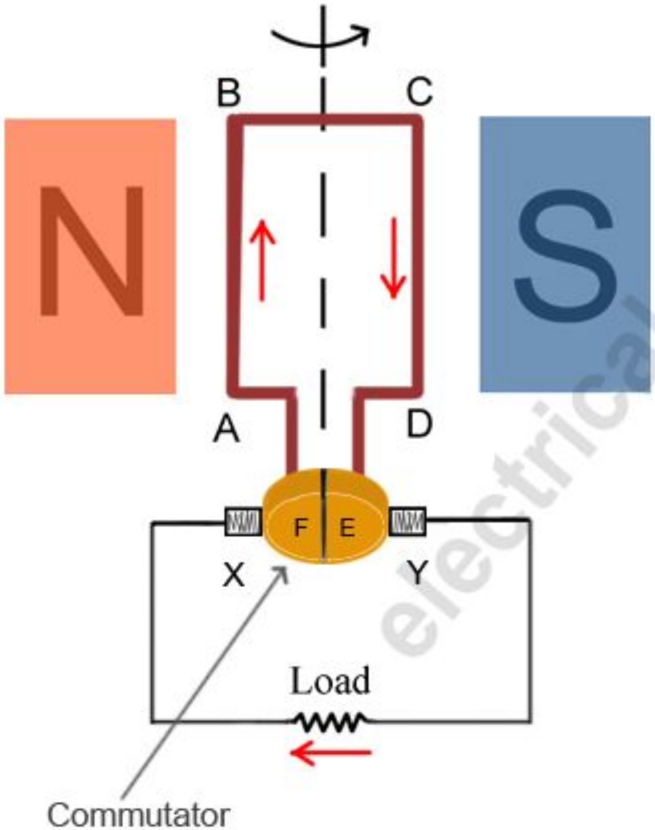
LAP WINDING

WAVE WINDING

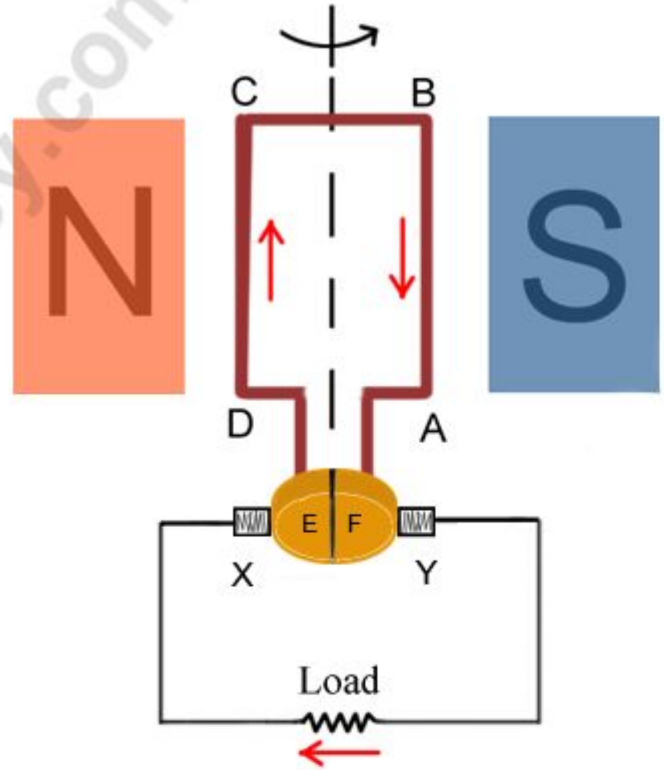

Lap winding
Wave winding


Lap winding
Wave winding
Conductors
Yb
Yf
Yr
Yc
Commutator
Yb
Yf
Yr
Yc

- ***Commutator and brushes*:**
  - Physical connection to the armature winding is made through a commutator-brush arrangement.
  - The ***function of a commutator***, in a dc generator, is to ***collect the current generated in armature conductors.***
  - Whereas, **in case of a dc motor**, commutator helps in ***providing current to the armature conductors***.
  - A ***commutator consists of a set of copper segments*** which are insulated from each other.

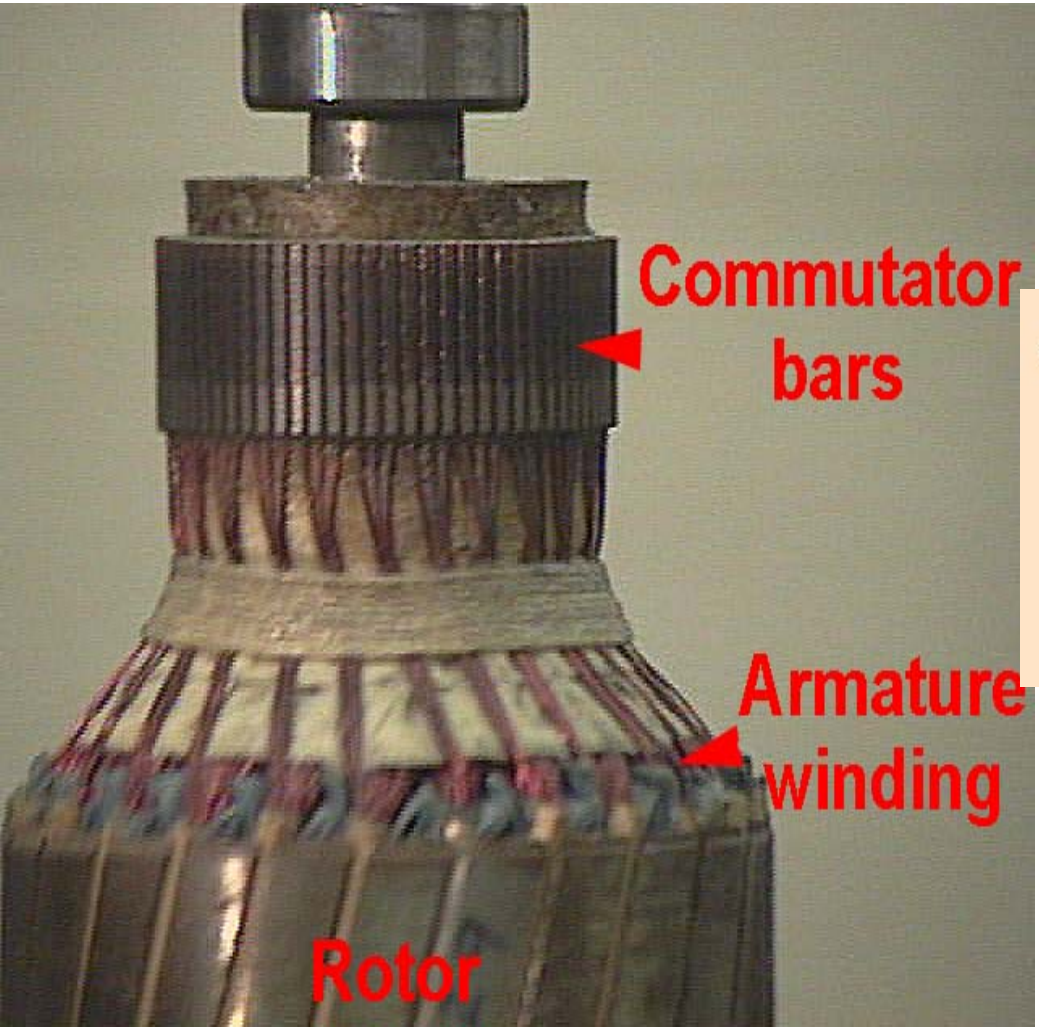


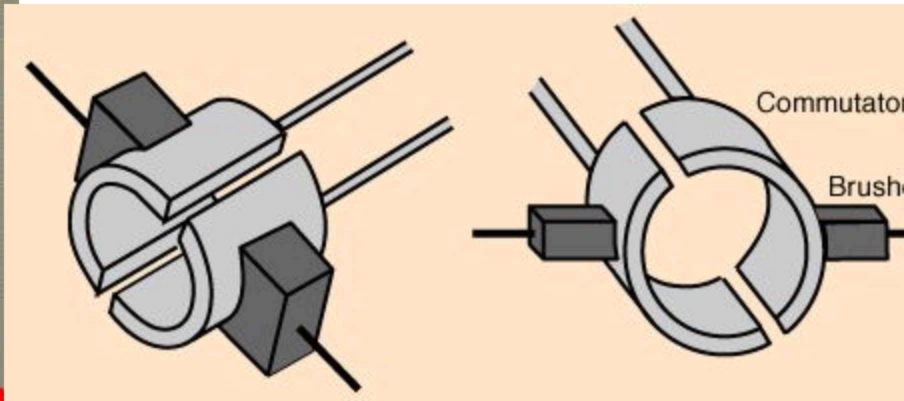
Case 1



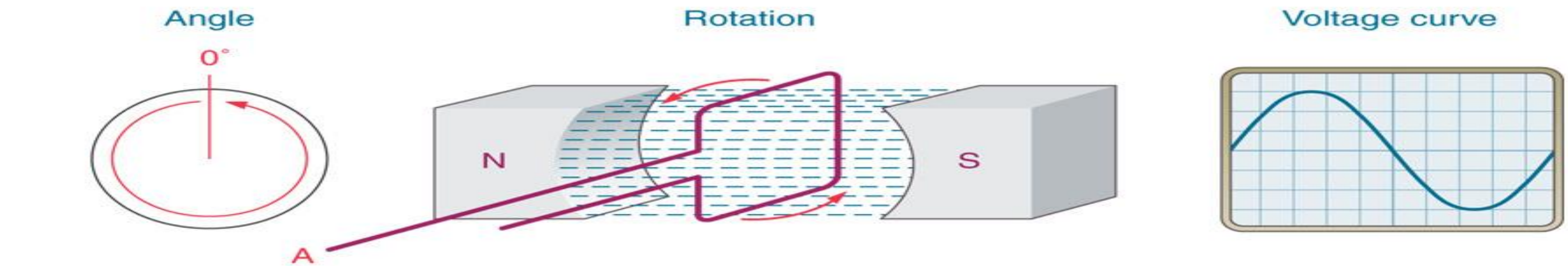
Case 2

Commutator

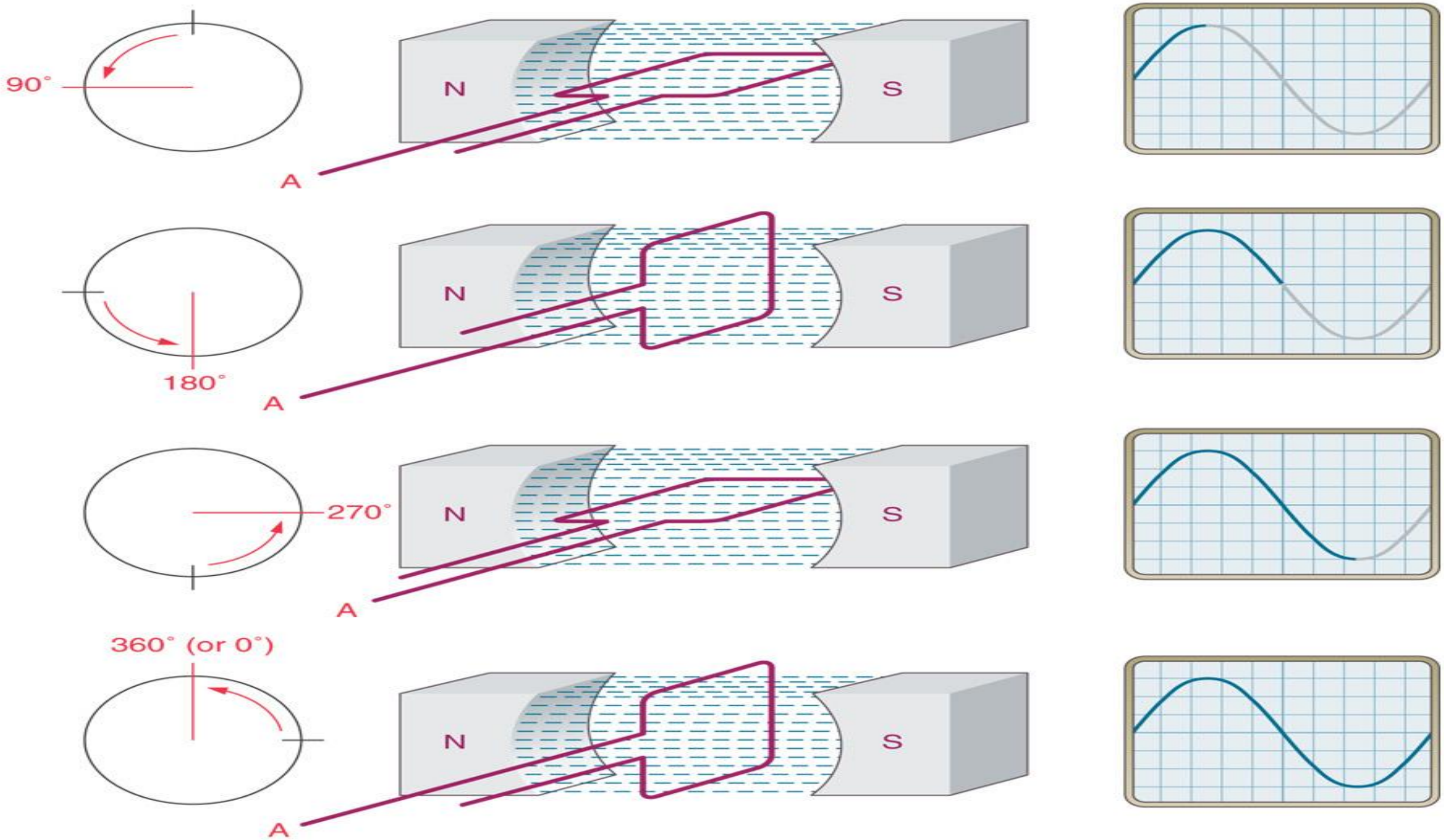

Commutator
bars
Armature
winding
Rotor


Commutator
Brushe

- A commutator is a mechanical rectifier which converts the alternating voltage generated in the armature winding into direct voltage across the brushes.
- The ***number of segments is equal to the number of armature coils.***
- Each segment is connected to an armature coil and the commutator is keyed to the shaft.
- *Brushes are usually made from carbon or graphite*. They rest on commutator segments and slide on the segments when the commutator rotates keeping the physical contact to collect or supply the current.

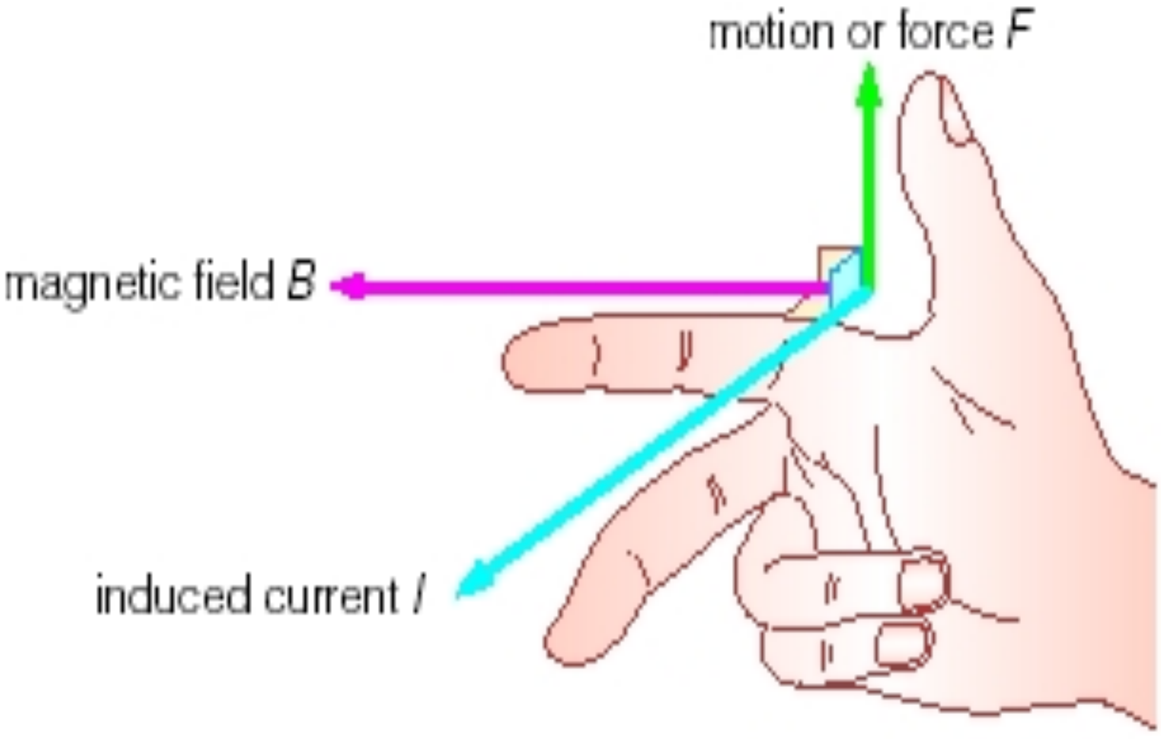


(a) One voltage cycle is produced by each rotation cycle of the rotor.



- **Working Principle Of A DC Generator:**
  - According to ***Faraday's laws of electromagnetic induction***, whenever a conductor is placed in a varying magnetic field (OR a conductor is moved in a magnetic field), an emf (electromotive force) gets induced in the conductor.
  - The **magnitude of induced emf** can be calculated from the emf equation of dc generator.
  - If the conductor is provided with the closed path, the induced current will circulate within the path.
  - In a DC generator, field coils produce an electromagnetic field and the armature conductors are rotated into the field.
  - Thus, an electromagnetically induced emf is generated in the armature conductors.
  - The direction of induced current is given by Fleming's right hand rule

Fleming's Right hand rule



- **Fleming's Right hand rule**
- Used to determine the direction of emf induced in a conductor
- The middle finger , the fore finger and thumb of the right hand are kept at right angles to one another
- The fore finger represent the direction of magnetic field
- The thumb represent the direction of motion of the conductor
- The middle finger will indicate the direction of the inducted emf

Types Of A DC Generator

- DC generators can be classified in two main categories
  - (i) Separately excited
  - (ii) Self-excited.

Separately excited:

In this type, field coils are energized from an independent external DC source.

- **Selfexcited**

In this type, field coils are energized from the current produced by the generator itself.

Self Exited DC Generator

- These are the generators whose field magnets are energized by the current supplied by themselves.
- In these type of machines field coils are internally connected with the armature. Due to residual magnetism some flux is always present in the poles.
- When the armature is rotated some emf is induced. Hence some induced current is produced. This small current flows through the field coil as well as the load and thereby strengthening the pole flux.

- As the pole flux strengthened, it will produce more armature emf, which cause further increase of current through the field. This increased field current further raises armature emf and this cumulative phenomenon continues until the excitation reaches to the rated value.

According To The Position Of The Field Coil DC Generator Has A Three Type

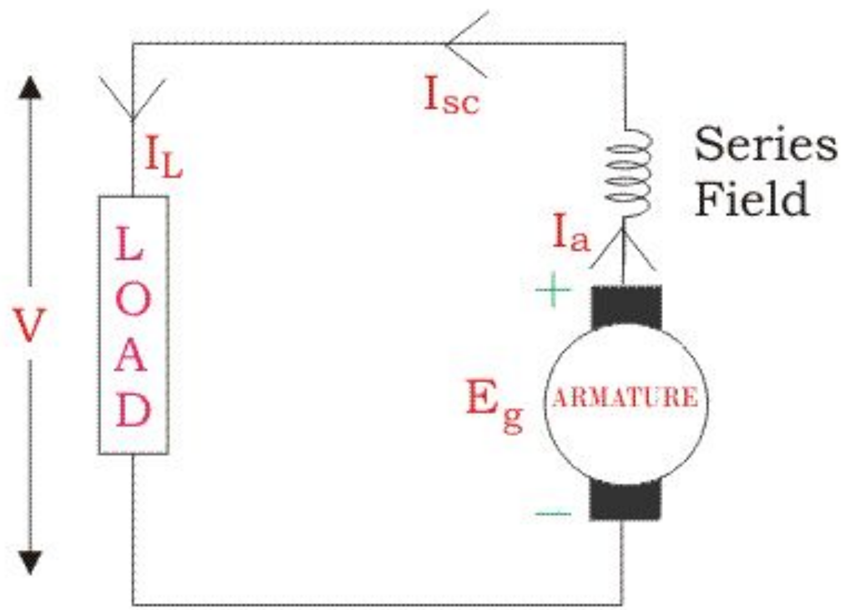
1) Series Generator

2) Shunt Generator

3) Compound Generator

Series Generator

- In these type of generators, the field windings are connected in series with armature conductors.
- So, whole current flows through the field coils as well as the load. As series field winding carries full load current it is designed with relatively few turns of thick wire.
- The Electrical resistance of series field winding is therefore very low (nearly 0.5Ω).



Series Wound Generator

Shunt Generator

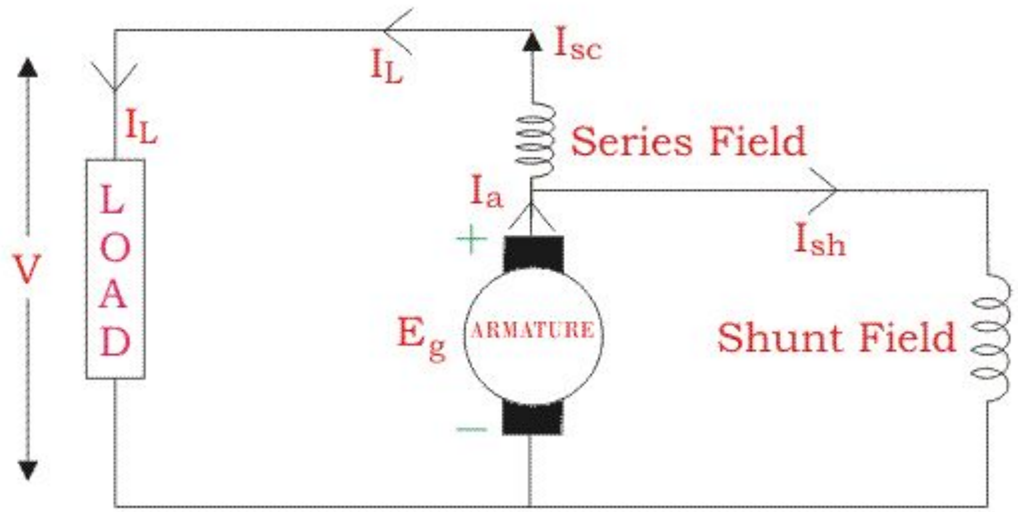
- In these type of generators, the field windings are connected in Parallel with armature conductors.
- In shunt generators the voltage in the field winding is same as the voltage across the terminal.
- Here armature current I_a is dividing in two parts, one is shunt field current I_{sh} and another is load current I_L.
- So, $I_a = I_{sh} + I_L$ The effective power across the load will be maximum when I_L will be maximum.
- So, it is required to keep shunt field current as small as possible. For this purpose the resistance of the shunt field, winding generally kept high (100 Ω) and large no of turns are used for the desired emf.

Compound DC Generator

- In series wound generators, the output voltage is directly proportional with load current. In shunt wound generators, output voltage is inversely proportional with load current. A combination of these two types of generators can overcome the disadvantages of both. This combination of windings is called compound wound DC generator.
- Compound wound generators have both series field winding and shunt field winding.
- One winding is placed in series with the armature and the other is placed in parallel with the armature.

Short Shunt Compound Wound DC Generator

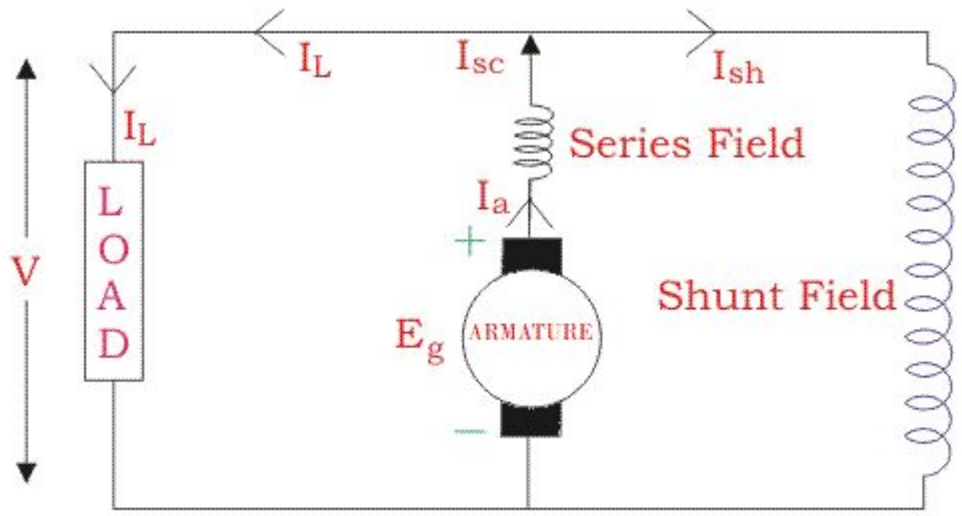
The generators in which only shunt field winding is in parallel with the armature winding as shown in figure.



Short Shunt Compound Wound Generator

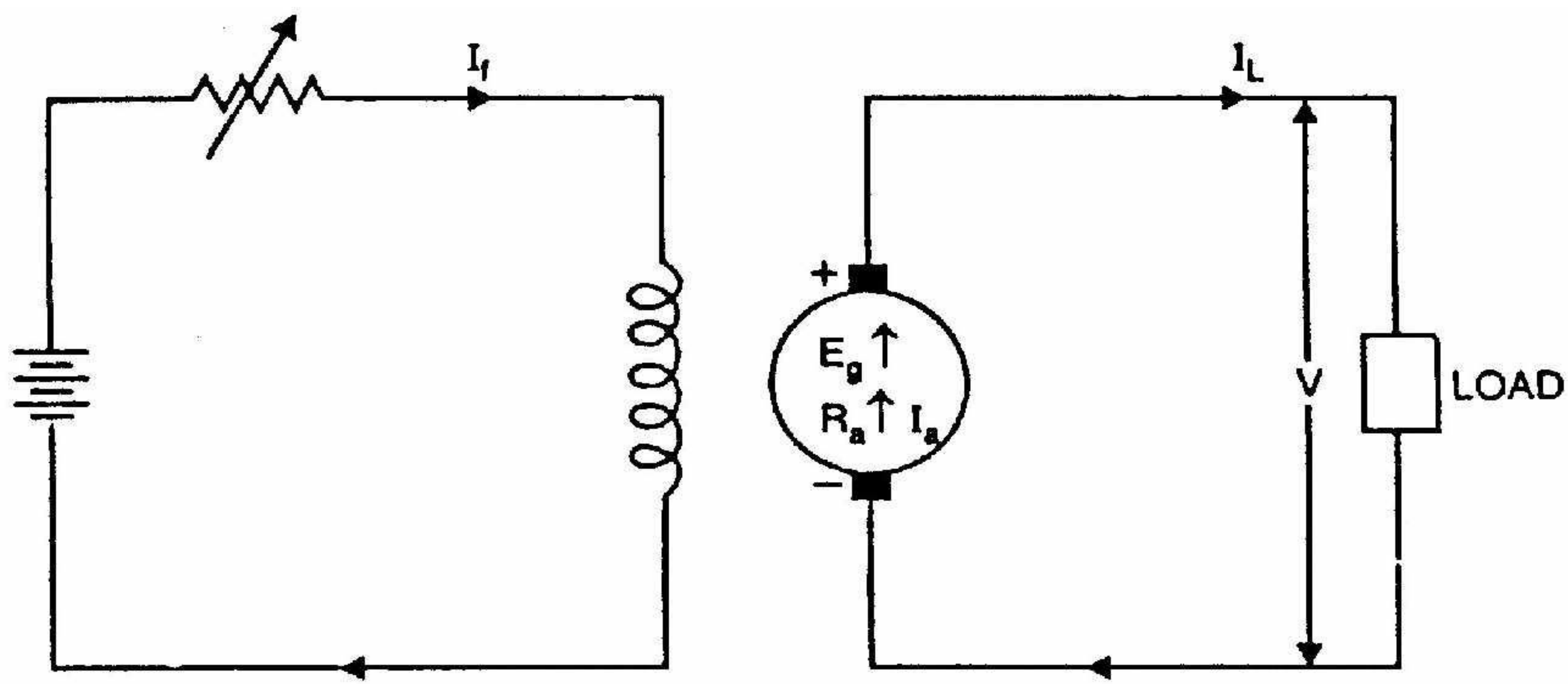
Long Shunt Compound Wound DC Generator

The generators in which shunt field winding is in parallel with both series field and armature winding as shown in figure



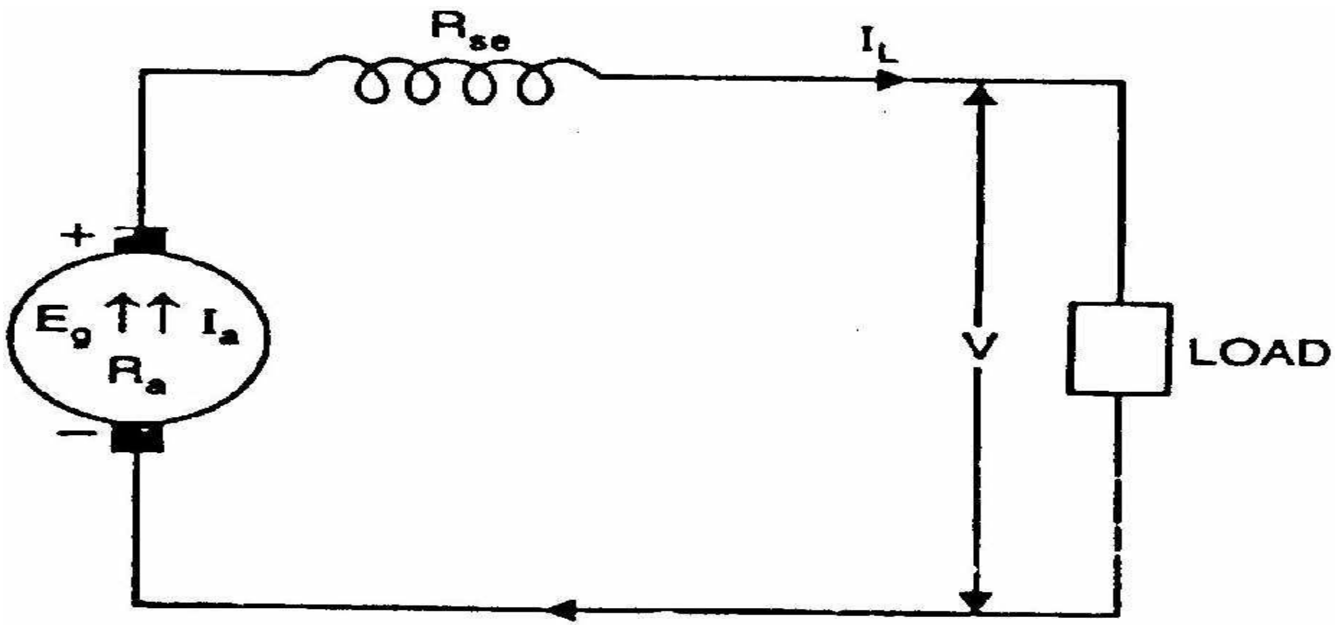
Long Shunt Compound Wound Generator

Separately excited DC generators



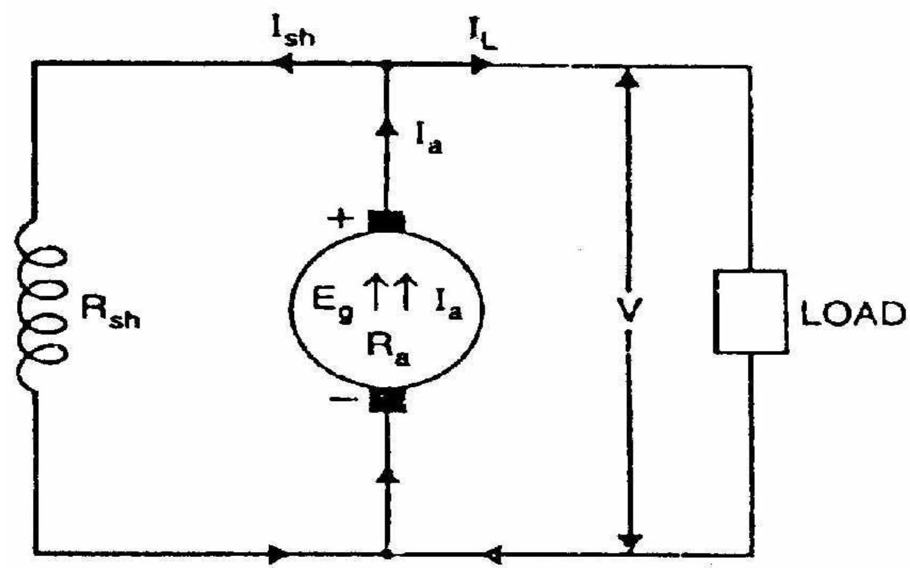
Armature current $I_a = I_L$
Terminal voltage $V_L = E_g - I_a R_a$
Electric power developed = $E_g I_a$
Power delivered to load = $E_g I_a$ - Ia $R_a = I_a(E_g - I_a R_a) = I_a V_L$

Series Generator



Armature current $I_a = I_{se} = I_L$
Terminal voltage $V_L = E_g - I_a (R_a + R_{se})$
Electric power developed = $E_g I_a$
Power delivered to load = $E_g I_a$ - Ia $(R_a + R_{se}) = I_a E_g - I_a (R_a + R_{se}) = I_a V_L$

Shunt generator



- Shunt field current $I_{sh}= V_L/R_{sh}$
- Armature current $I_a = I_L + I_{sh}$
- Terminal voltage $V_L= E_g - I_a R_a$
- Electric power developed = $E_g I_a$
- Power delivered to load = $V_L I_L$

MNA And GNA

EMF is induced in the armature conductors when they cut the magnetic field lines. There is an axis (or, you may say, a plane) along which armature conductors move parallel to the flux lines and, hence, they do not cut the flux lines while on that plane. MNA (Magnetic Neutral Axis) may be defined as the axis along which no emf is generated in the armature conductors as they move parallel to the flux lines. Brushes are always placed along the MNA because reversal of current in the armature conductors takes place along this axis.

GNA (Geometrical Neutral Axis) may be defined as the axis which is perpendicular to the stator field axis.

Armature Reaction

In DC motor or DC generator two windings are use: 1. Field winding 2.Armature winding.

The purpose of field winding is to produce magnetic field (main flux), whereas the purpose of armature winding is to carry armature current. Although the armature winding is not provided for the purpose of producing a magnetic field, still the current in the armature winding also produces a magnetic flux (armature flux).

The armature flux is distorts and weakens the main flux. these effect of armature flux on the main flux is called armature reaction in a dc generator.

The Adverse Effects Of Armature Reaction:

1. Armature reaction weakens the main flux. In case of a dc generator, weakening of the main flux reduces the generated voltage.

2. Armature reaction distorts the main flux, hence the position of M.N.A. gets shifted (M.N.A. is perpendicular to the flux lines of main field flux). Brushes should be placed on the M.N.A., otherwise, it will lead to sparking at the surface of brushes.

So, due to armature reaction, it is hard to determine the exact position of the MNA For a loaded dc generator, MNA will be shifted in the direction of the rotation. On the other hand, for a loaded dc motor, MNA will be shifted in the direction opposite to that of the rotation.

How To Reduce Armature Reaction?

Usually, no special efforts are taken for small machines (up to few kilowatts) to reduce the armature reaction. But for large DC machines, compensating winding and interpoles are used to get rid of the ill effects of armature reaction

Emf Equation of a DC Generator

As the armature rotates, a voltage is generated in its coils. In the case of a generator, the emf of rotation is called the Generated emf or Armature emf and is denoted as Er = Eg. In the case of a motor, the emf of rotation is known as Back emf or Counter emf and represented as Er = Eb. The expression for emf is same for both the operations. I.e., for Generator as well as for Motor

Derivation of EMF Equation of a DC Machine – Generator and Motor

Let,

- **P** – Number of poles of the machine
- **ϕ** – Flux per pole in Weber.
- **Z** – Total number of armature conductors.
- **N** – Speed of armature in revolution per minute (r.p.m).
- **A** – Number of parallel paths in the armature winding.

In one revolution of the armature, the flux cut by one conductor is given as

$$\text{Flux cut by one conductor} = P\varphi \quad \text{wb} \ldots \ldots (1)$$

Time taken to complete one revolution is given as

$$t = \frac{60}{N} \text{ seconds } \ldots\ldots(2)$$

Therefore, the average induced e.m.f in one conductor will be

$$e = \frac{P\varphi}{t} \ldots\ldots(3)$$

Putting the value of (t) from Equation (2) in the equation (3) we will get

$$e = \frac{P\varphi}{60/N} = \frac{P\varphi N}{60} \text{ volts } \ldots\ldots(4)$$

The number of conductors connected in series in each parallel path = Z/A.

Therefore, the average induced e.m.f across each parallel path or the armature terminals is given by the equation shown below.

$$E = \frac{P\varphi N}{60} \times \frac{Z}{A} = \frac{PZ\varphi N}{60\ A} \text{ volts or}$$

$$E = \frac{PZ\varphi n}{A} \ldots\ldots(5)$$

Where n is the speed in revolution per second (r.p.s) and given as

$$n = \frac{N}{60}$$

For a given machine, the number of poles and the number of conductors per parallel path (Z/A) are constant. Hence, the equation (5) can be written as

$$E = K\varphi n$$

Where, K is a constant and given as

$$K = \frac{PZ}{A}$$

Therefore, the average induced emf equation can also be written as

$$E \propto \varphi n \quad \text{or}$$

$$E = K_1 \varphi N$$

Where K_1 is another constant and hence induced emf equation can be written as

$$E \propto \varphi N \quad \text{or}$$

$$E \propto \varphi \omega$$

Where ω is the angular velocity in radians/second is represented as

$$\omega = \frac{2\pi N}{60}$$

Thus, it is clear that the induced emf is directly proportional to the speed and flux per pole. The polarity of induced emf depends upon the direction of the magnetic field and the direction of rotation. If either of the two is reverse the polarity changes, but if two are reversed the polarity remains unchanged.

This induced emf is a fundamental phenomenon for all the DC Machines whether they are working as a generator or motor.

If the machine DC Machine is working as a Generator, the induced emf is given by the equation shown below.

$$E_g = \frac{PZ\,\varphi\,N}{60\,A} \quad \text{volts}$$

Where **E_g** is the **Generated Emf**

If the machine DC Machine is working as a Motor, the induced emf is given by the equation shown below.

$$E_b = \frac{PZ\,\varphi\,N}{60\,A} \quad \text{volts}$$

In a motor, the induced emf is called **Back Emf (E_b)** because it acts opposite to the supply voltage.

Characteristics of DC generators

Generally, following three Characteristics of DC generators are taken into considerations:

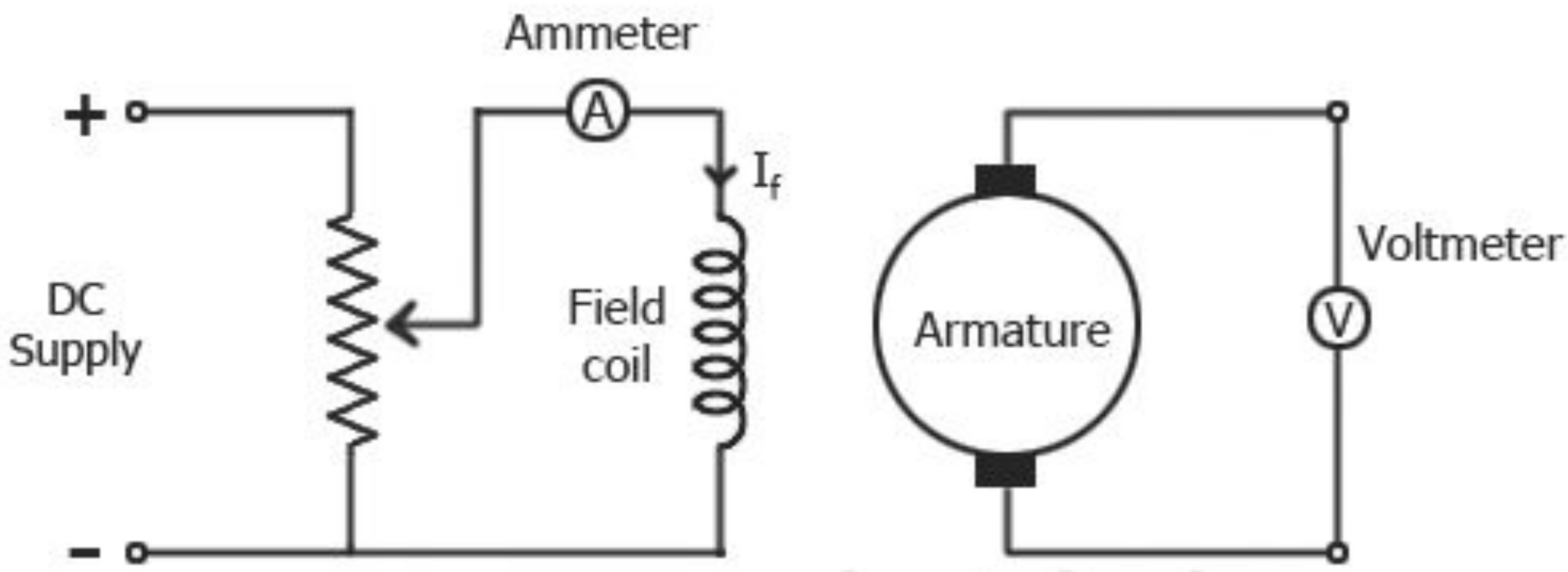
(i)Open Circuit Characteristic (O.C.C.),

(ii) Internal or Total Characteristic

iii) External Characteristic.

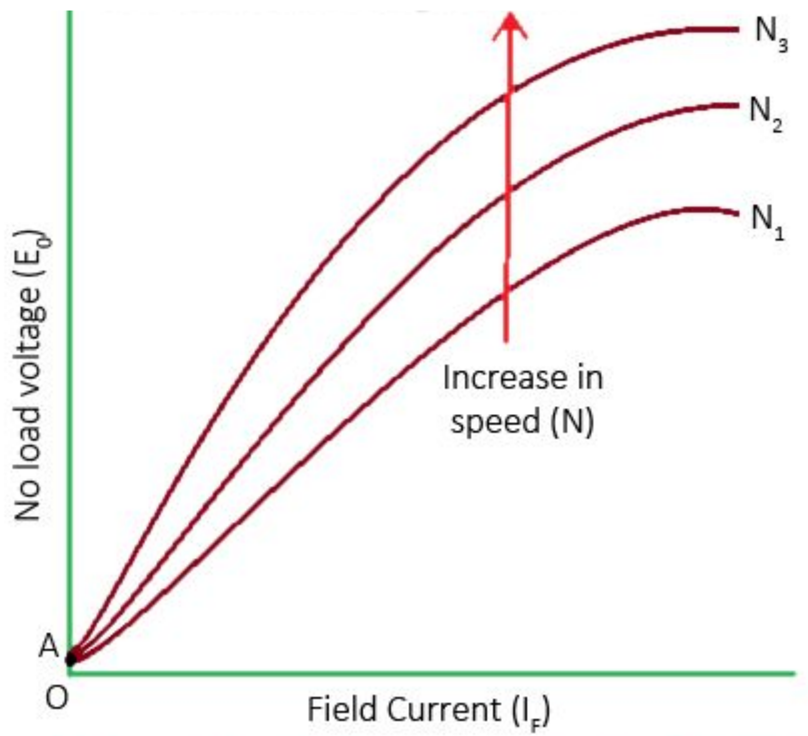
Open Circuit Characteristic (O.C.C.) (E0/If)

Open circuit characteristic is also known as magnetic characteristic or no-load saturation characteristic. This characteristic shows the relation between generated emf at no load (E0) and the field current (If) at a given fixed speed. The O.C.C. curve is just the magnetization curve and it is practically similar for all type of generators. The data for O.C.C. curve is obtained by operating the generator at no load and keeping a constant speed. Field current is gradually increased and the corresponding terminal voltage is recorded. The connection arrangement to obtain O.C.C. curve is as shown in the figure below. For shunt or series excited generators, the field winding is disconnected from the machine and connected across an external supply.



Now, from the emf equation of dc generator, we know that Eg = kϕ. Hence, the generated emf should be directly proportional to field flux (and hence, also directly proportional to the field current). However, even when the field current is zero, some amount of emf is generated (represented by OA in the figure below). This initially induced emf is due to the fact that there exists some residual magnetism in the field poles. Due to the residual magnetism, a small initial emf is induced in the armature. This initially induced emf aids the existing residual flux, and hence, increasing the overall field flux.

This consequently increases the induced emf. Thus, O.C.C. follows a straight line. However, as the flux density increases, the poles get saturated and the ϕ becomes practically constant. Thus, even we increase the If further, ϕ remains constant and hence, Eg also remains constant.



Open Circuit Characteristic (O.C.C.)

INTERNAL OR TOTAL CHARACTERISTIC (Eg/Ia)

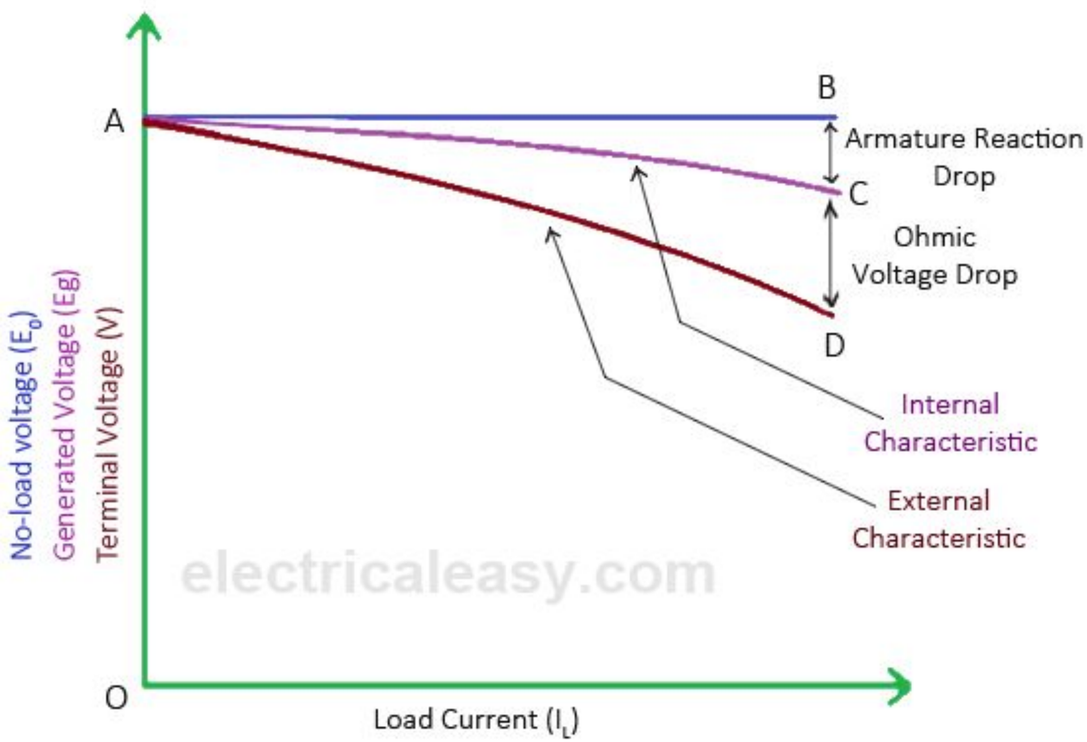
An internal characteristic curve shows the relation between the on-load generated emf (Eg) and the armature current (Ia). The on-load generated emf Eg is always less than E0 due to the armature reaction. Eg can be determined by subtracting the drop due to demagnetizing effect of armature reaction from no-load voltage E0. Therefore, internal characteristic curve lies below the O.C.C. curve.

External Characteristic (V/IL)

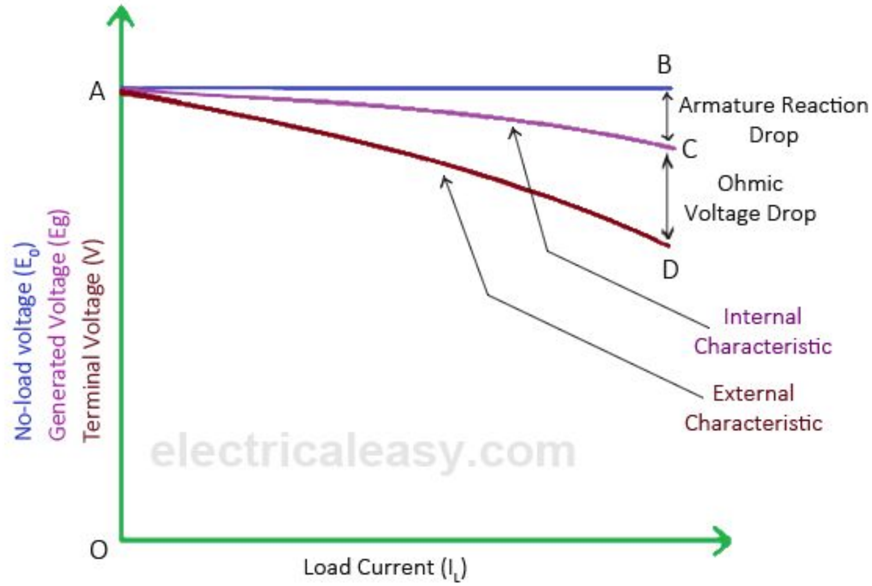
An external characteristic curve shows the relation between terminal voltage (V) and the load current (IL). Terminal voltage V is less than the generated emf Eg due to voltage drop in the armature circuit. Therefore, external characteristic curve lies below the internal characteristic curve.

External characteristics are very important to determine the suitability of a generator for a given purpose. Therefore, this type of characteristic is sometimes also called as performance characteristic or load characteristic. Internal and external characteristic curves are shown below for each type of generator.

CHARACTERISTICS OF SEPARATELY EXCITED DC GENERATOR



Characteristics of separately excited DC generator



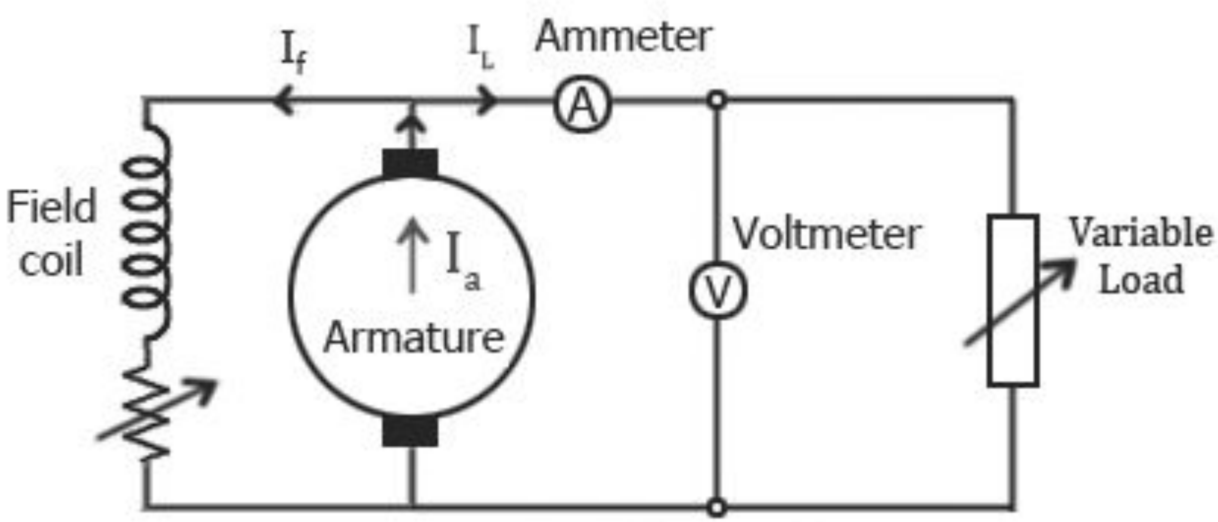
Characteristics of separately excited DC generator

If there is no armature reaction and armature voltage drop, the voltage will remain constant for any load current. Thus, the straight line AB in above figure represents the no-load voltage vs. load current IL.

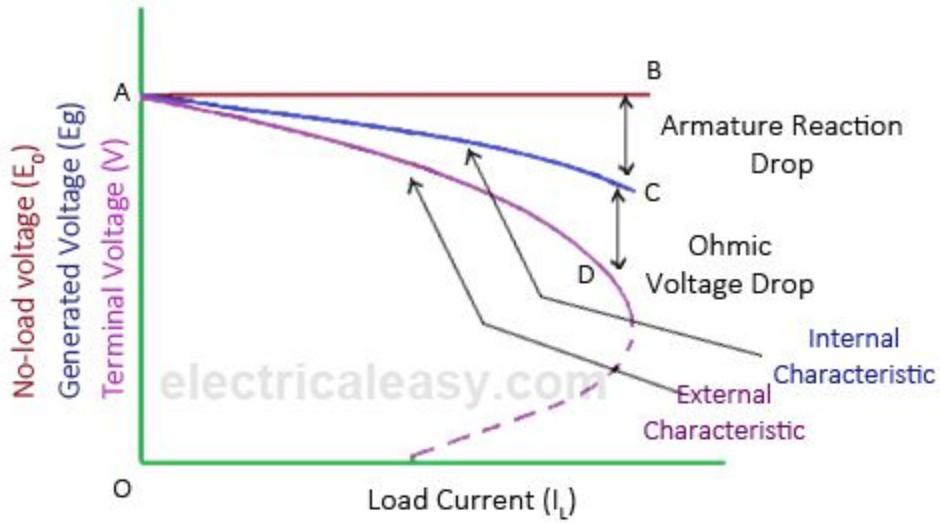
Due to the demagnetizing effect of armature reaction, the on-load generated emf is less than the no-load voltage. The curve AC represents the on-load generated emf Eg vs. load current IL i.e. internal characteristic (as Ia = IL for a separately excited dc generator). Also, the terminal voltage is lesser due to ohmic drop occurring in the armature and brushes. The curve AD represents the terminal voltage vs. load current i.e. external characteristic.

CHARACTERISTICS OF DC SHUNT GENERATOR

To determine the internal and external load characteristics of a DC shunt generator the machine is allowed to build up its voltage before applying any external load. To build up voltage of a shunt generator, the generator is driven at the rated speed by a prime mover. Initial voltage is induced due to residual magnetism in the field poles. The generator builds up its voltage as explained by the O.C.C. curve. When the generator has built up the voltage, it is gradually loaded with resistive load and readings are taken at suitable intervals. Connection arrangement is as shown in the figure below.



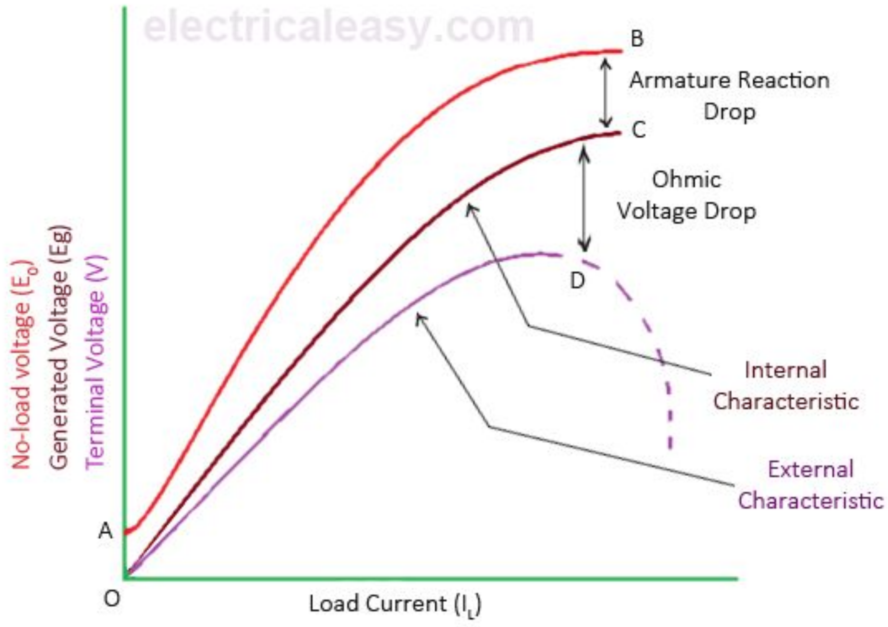
Unlike, separately excited DC generator, here, $I_L \neq I_a$. For a shunt generator, $I_a = I_L + I_f$. Hence, the internal characteristic can be easily transmitted to Eg vs. I_L by subtracting the correct value of I_f from I_a.



Characteristics of DC shunt generator

During a normal running condition, when load resistance is decreased, the load current increases. But, as we go on decreasing the load resistance, terminal voltage also falls. So, load resistance can be decreased up to a certain limit, after which the terminal voltage drastically decreases due to excessive armature reaction at very high armature current and increased I2R losses. Hence, beyond this limit any further decrease in load resistance results in decreasing load current. Consequently, the external characteristic curve turns back as shown by dotted line in the above figure.

Characteristics of DC Series Generator



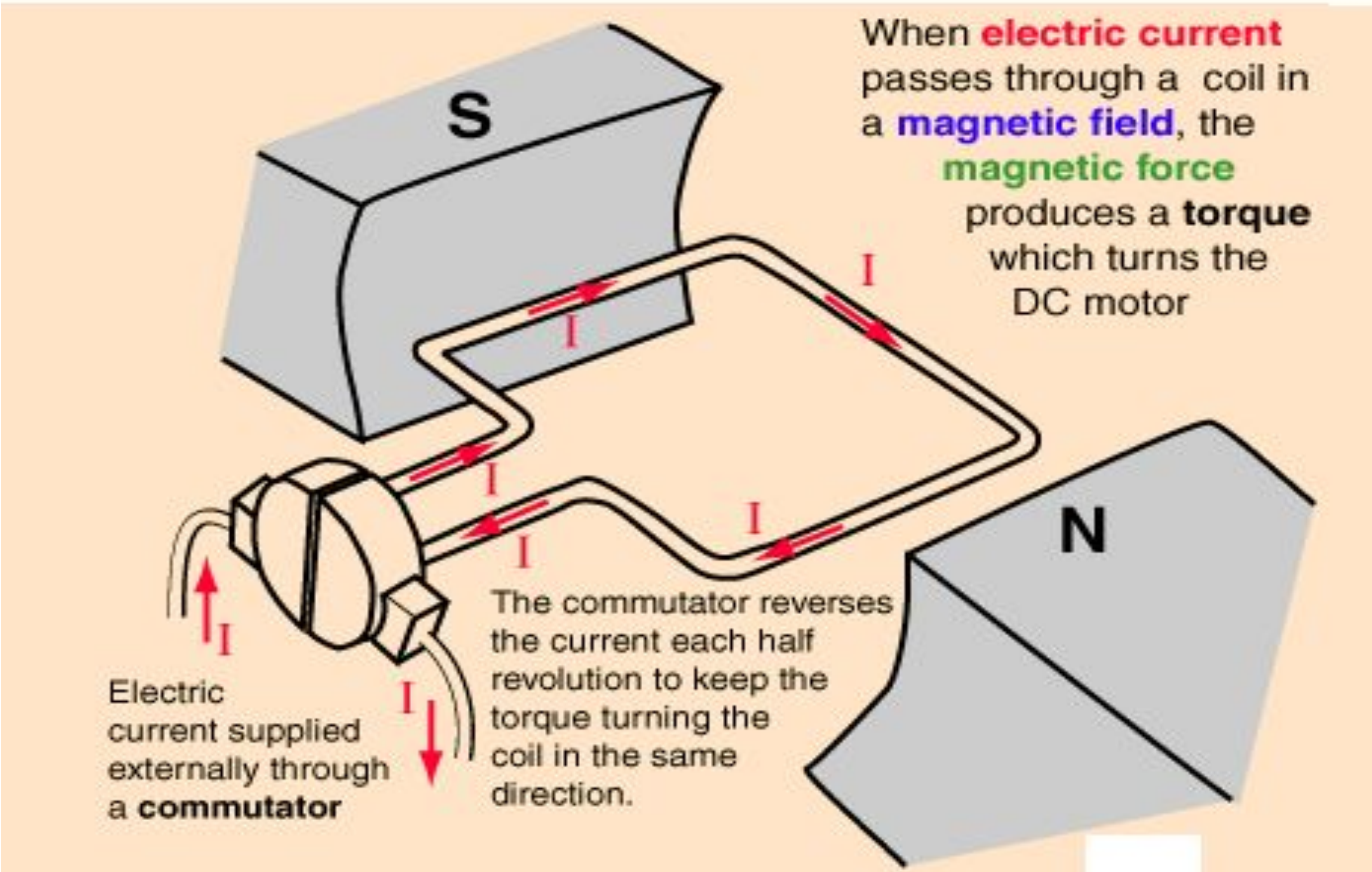
Characteristics of DC series generator

The curve AB in above figure identical to open circuit characteristic (O.C.C.) curve. This is because in DC series generators field winding is connected in series with armature and load. Hence, here load current is similar to field current (i.e. I_L=I_f). The curve OC and OD represent internal and external characteristic respectively. In a DC series generator, terminal voltage increases with the load current. This is because, as the load current increases, field current also increases. However, beyond a certain limit, terminal voltage starts decreasing with increase in load. This is due to excessive demagnetizing effects of the armature reaction.

DC MOTOR

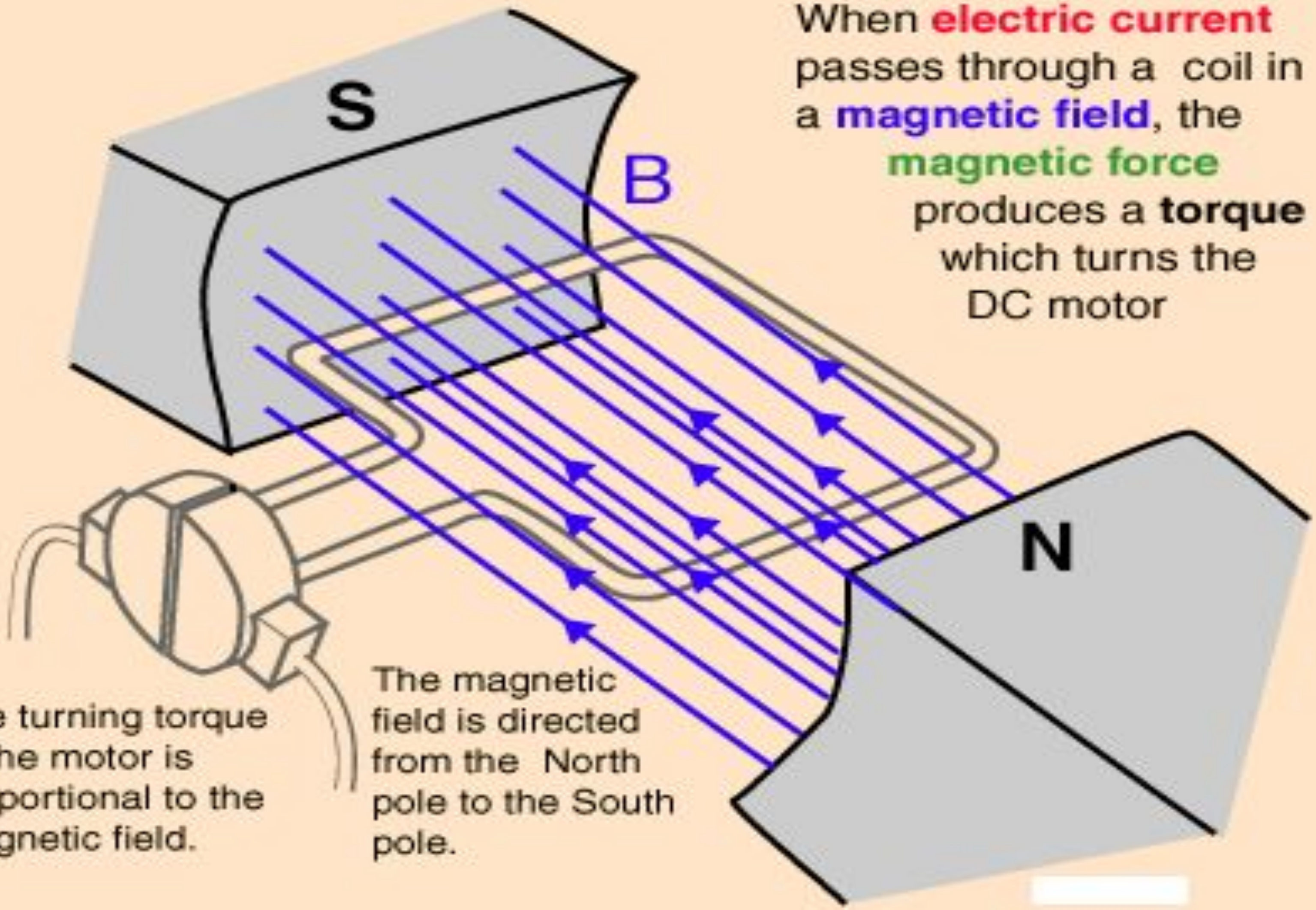
- Construction
- Working principle of DC motor
- Types of DC motor
- Application of DC motor

Current in DC Motor



Magnetic Field in DC Motor

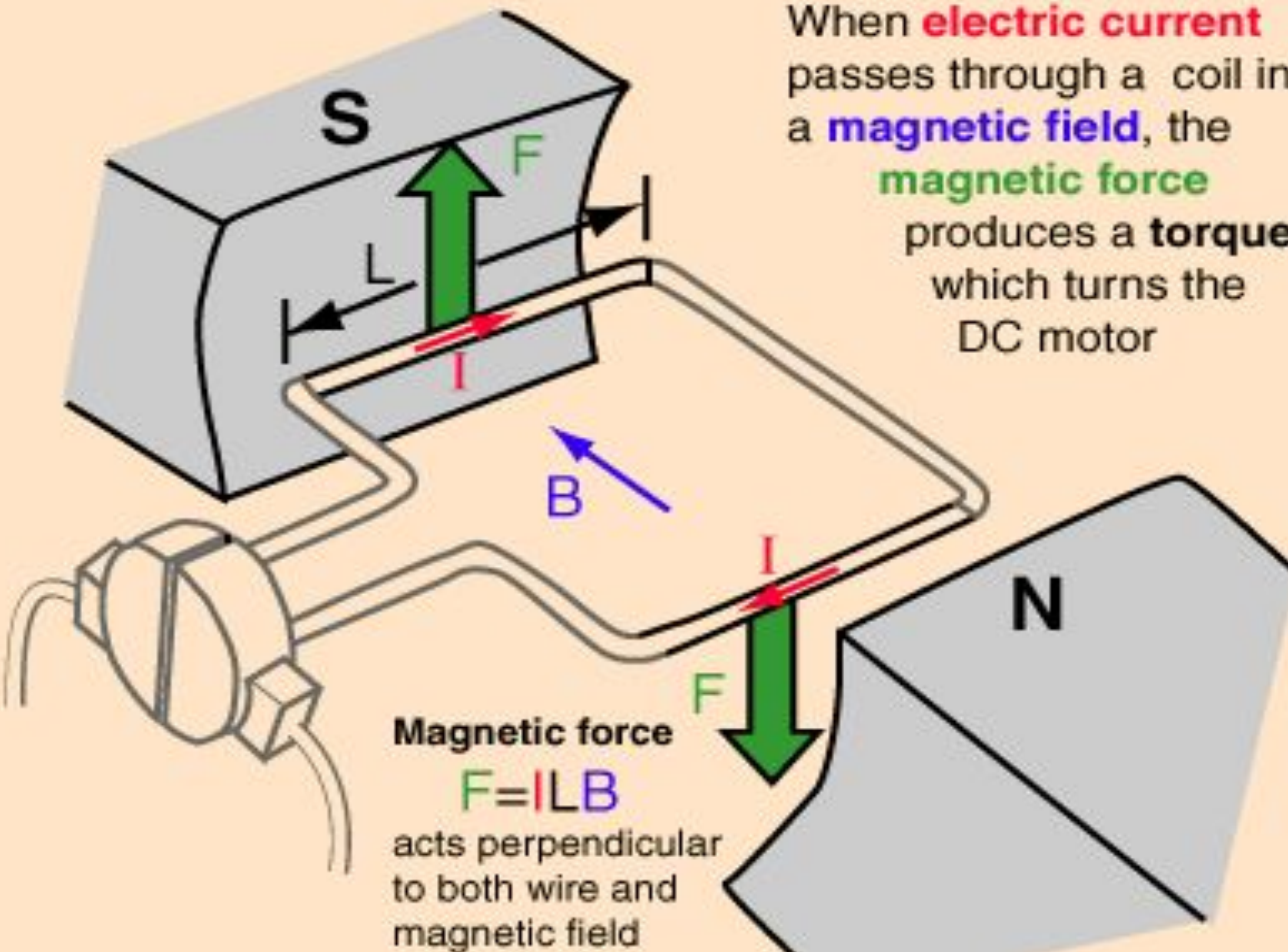
When **electric current** passes through a coil in a **magnetic field**, the **magnetic force** produces a **torque** which turns the DC motor



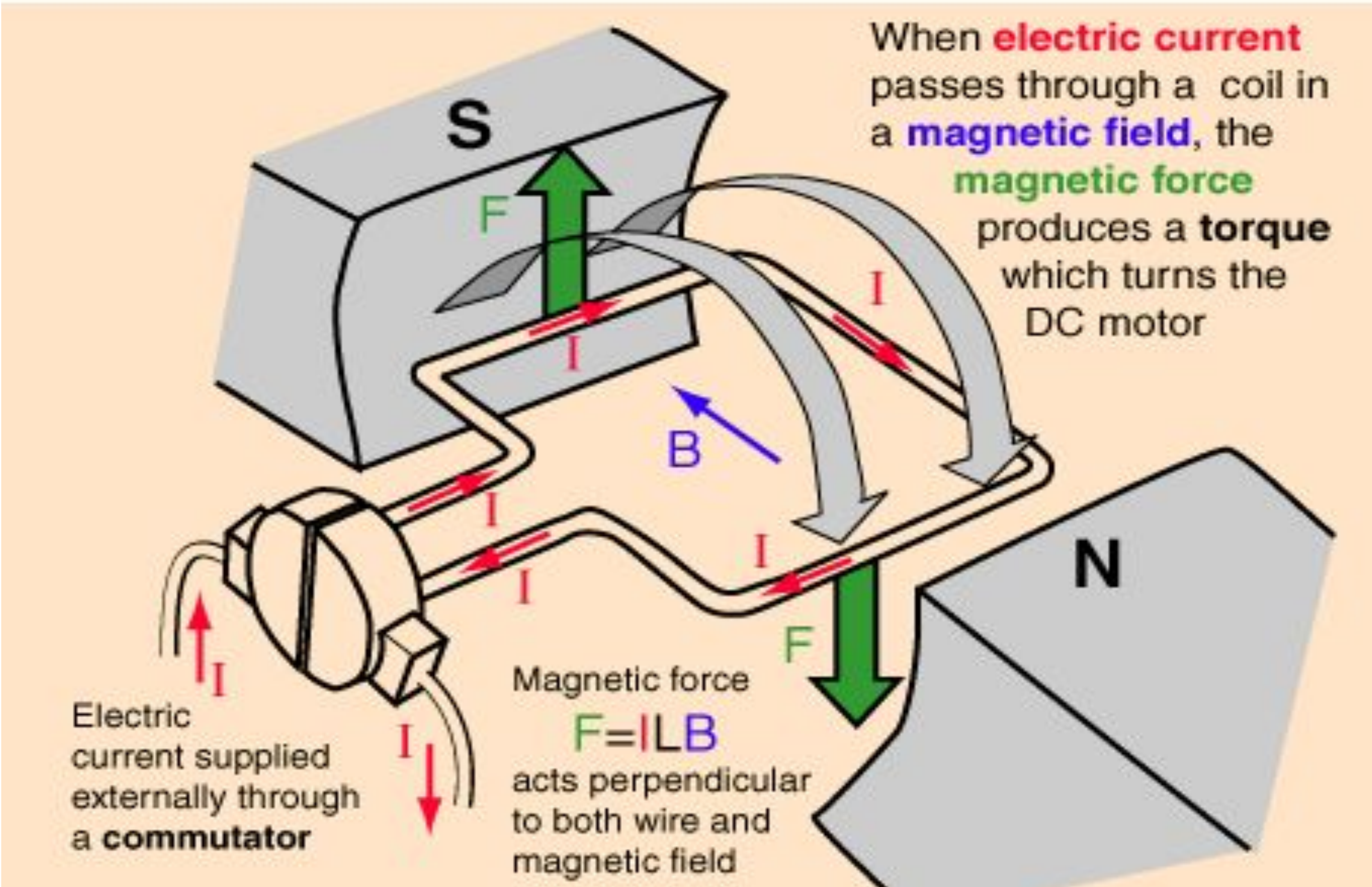
The turning torque of the motor is proportional to the magnetic field.

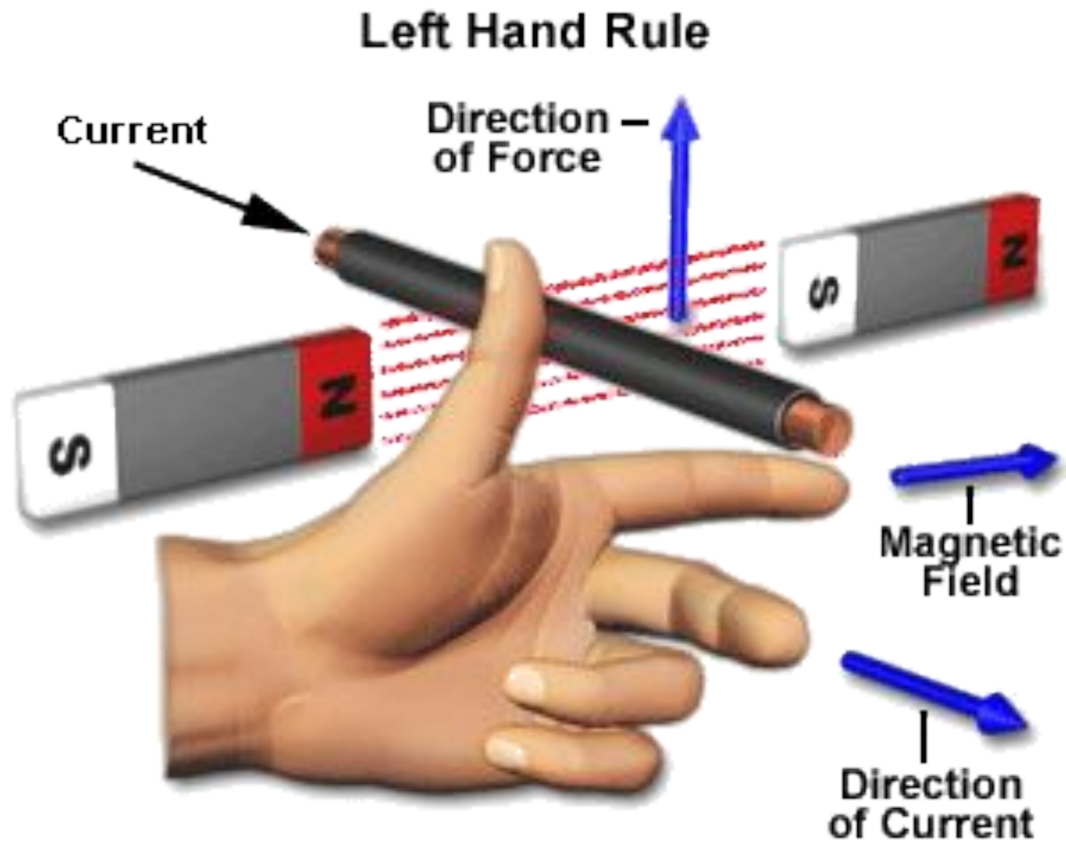
The magnetic field is directed from the North pole to the South pole.

Force in DC Motor



DC Motor Operation

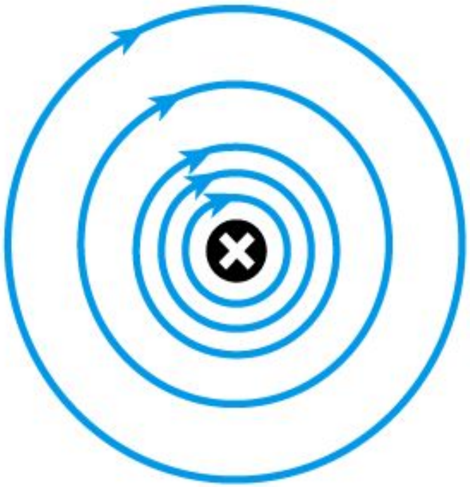




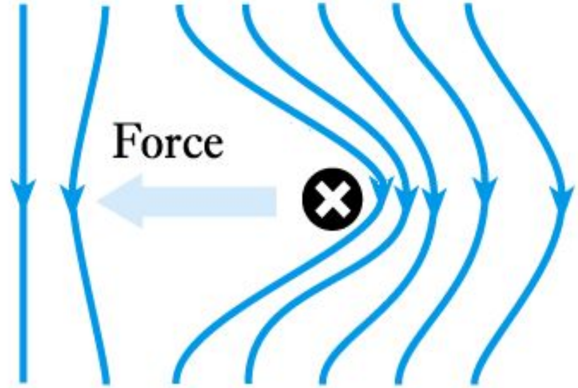
whenever an current carrying conductor is placed inside a magnetic field, a force acts on the conductor, in a direction perpendicular to both the directions of the current and the magnetic field.

- **Working Principle Of A DC Motor**
  - A motor is an electrical machine which converts electrical energy into mechanical energy.
  - The **principle of working of a DC motor**
    - is that "*whenever a current carrying conductor is placed in a magnetic field, it experiences a mechanical force".*
  - The direction of this force is given by Fleming's left hand rule and
  - it's magnitude is given by $F = BIL$.
    - Where, B = magnetic flux density,
    - I = current and
    - L = length of the conductor within the magnetic field.

- When current flows in a conductor it produces a magnetic field about it - as shown in (a) below
  - when the current-carrying conductor is within an externally generated magnetic field, the fields interact and a force is exerted on the conductor - as in (b)



(a) The magnetic field about a current flowing into the page



(b) The effects of an external magnetic field

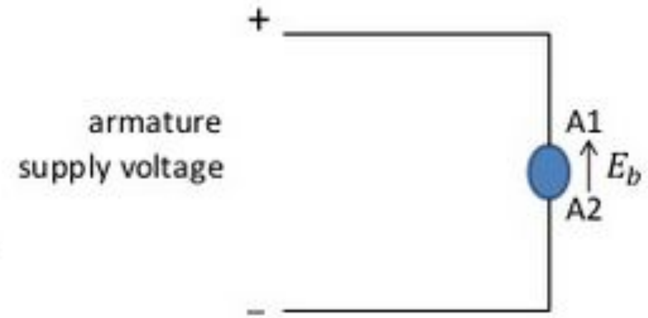
- **Fleming's left hand rule**:
  - If we stretch the first finger, second finger and thumb of our left hand to be perpendicular to each other
  - **Direction of Magnetic Field** is represented by the **first finger,**
  - **Direction of the Current** is represented by **second finger**
  - **Direction of the Force** is represented **by Thumb**

Back emf:

- When the armature winding of dc motor is start rotating in the magnetic flux produced by the field winding, it cuts the lines of magnetic flux and induces the emf in the armature winding.
- According to Lenz's law (*The law that whenever there is an induced electromotive force (emf) in a conductor, it is always in such a direction that the current it would produce would oppose the change which causes the induced emf.*), this induced emf acts in the opposite direction to the armature supply voltage. Hence this emf is called as back emfs.

$$E_b = \frac{N\emptyset Z}{60}\frac{P}{A}\text{ Volts}$$

N= speed in rpm
$\emptyset$= flux per pole
Z= no of conductors
P=no of pole pairs
A=area of cross section of conductor
E_b= back emf



Voltage and Power equation of DC Motor:

$$V = Eb + IaRa$$

If we multiply the above equation by Ia, we will get

$$VIa = EbIa + Ia^2 Ra$$

$VIa = electrical\ power\ supplied\ to\ the\ motor$
$EbIa = electrical\ equivalent\ of\ the\ mechanical\ power\ produced\ by\ the\ motor$
$Ia^2 Ra = power\ loss\ taking\ place\ in\ armature\ winding$
Thus,

$$EbIa = VIa - Ia^2 Ra$$

=input power-power loss

thus, $EbIa$= Gross mechanical power produce by the motor

= Pm

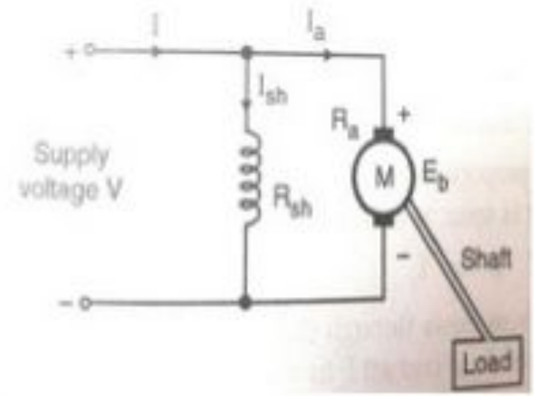
Types of DC Motor:

- Classification of the d.c. motor depends on the way of connecting the armature and field winding of a d.c. motor:

1. DC Shunt Motor
2. DC Series Motor
3. DC Compound Motor

- Short shunt compound
  - Cumulative compound motor
  - Differential compound motor
- long shunt compound
  - Cumulative compound motor
  - Differential compound motor

DC Shunt Motor:



- In dc shunt motor the armature and field winding are connected in parallel across the supply voltage
- The resistance of the shunt winding R_{sh} is always higher than the armature winding R_a
- Since V and R_{sh} both remains constant the I_{sh} remains essentially constant, as field current is responsible for generation of flux.

  thus $\quad \emptyset \propto I_{sh}$
- So shunt motor is also called as constant flux motor.

Torque and Speed equation of DC Shunt Motor:

As we have seen for dc motor

$$T \propto \emptyset Ia$$

But for dc shunt motor : $\emptyset \propto Ish$

And Ish is constant , thus $\emptyset$ is also constant

So torque in dc shunt motor is

$$T \propto Ia$$

For dc motor

$$Eb = \frac{N\emptyset ZP}{A60}$$

$Z\ , P, A, \emptyset\ and\ 60$ are constants

Thus, $N \propto Eb \propto (V - IaRa)$

Characteristics of DC Shunt Motor:

To study the performance of the DC shunt Motor various types of characteristics are to be studied.

1. Torque Vs Armature current characteristics.
2. Speed Vs Armature current characteristics.
3. Speed Vs Torque characteristics.

These characteristics are determined by keeping the following two relations in mind.

$T_a \propto \phi . I_a$ and **$N \propto E_b/\phi$**

These above equations can be studied at - emf and torque equation. For a DC motor, magnitude of the back emf is given by the same emf equation of a dc generator

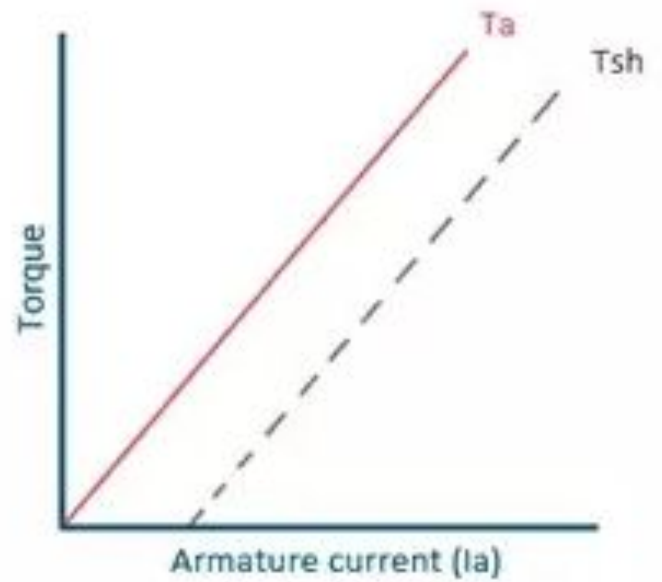
i.e.

$E_b = P\phi NZ / 60A$. For a machine, P, Z and A are constant, therefore, $N \propto E_b/\phi$

TORQUE VS. ARMATURE CURRENT (Ta-Ia)

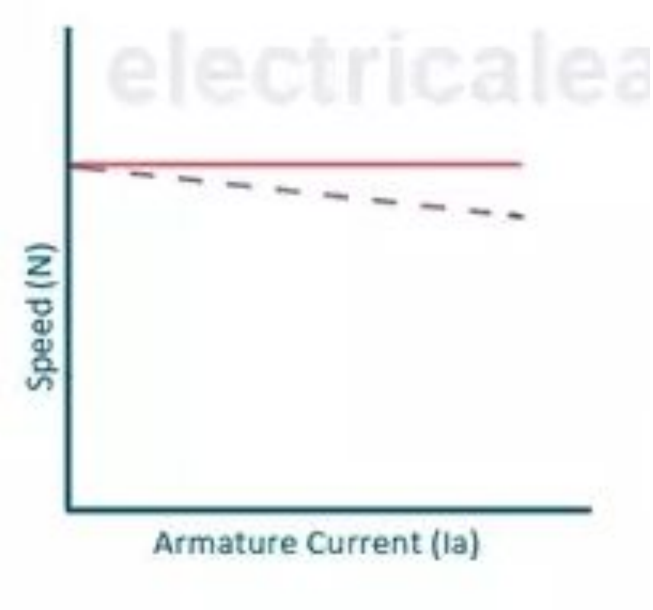
In DC shunt motors, we can assume the field flux ϕ to be constant. Though at heavy loads, ϕ decreases in a small amount due to increased armature reaction. As we are neglecting the change in the flux ϕ, we can say that torque is proportional to armature current. Hence, the Ta-Ia characteristic for a dc shunt motor will be a straight line through the origin.

Since heavy starting load needs heavy starting current, **shunt motor should never be started on a heavy load**.



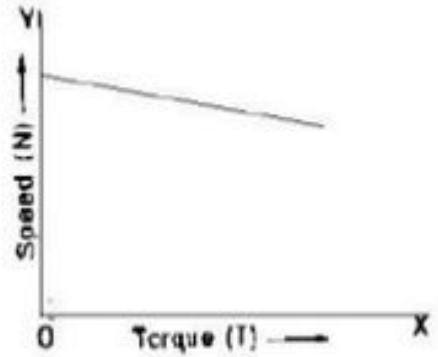
SPEED VS. ARMATURE CURRENT (N-Ia)

As flux ϕ is assumed to be constant, we can say N ∝ Eb. But, as back emf is also almost constant, the speed should remain constant. But practically, ϕ as well as Eb decreases with increase in load. Back emf Eb decreases slightly more than ϕ, therefore, the speed decreases slightly. Generally, the speed decreases only by 5 to 15% of full load speed. Therefore, **a shunt motor can be assumed as a constant speed motor**.



Speed Vs Torque characteristics of DC Shunt motor

- From the above two characteristics of dc shunt motor, the torque developed and speed at various armature currents of dc shunt motor may be noted.
- If these values are plotted, the graph representing the variation of speed with torque developed is obtained.
- This curve resembles the speed Vs current characteristics as the torque is directly proportional to the armature current.



Applications of DC shunt Motor:

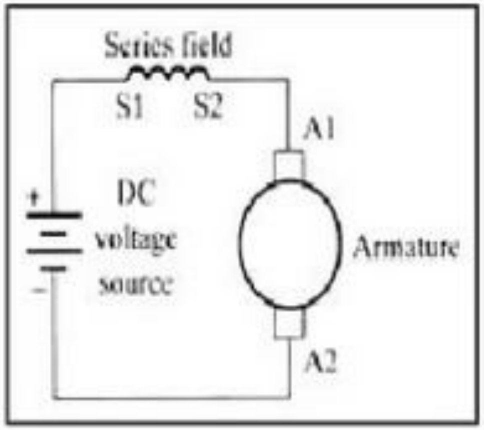
These motors are constant speed motors, hence used in applications requiring constant speed.

Like:

1) Lathe machine
2) Drilling machine
3) Grinders
4) Blowers
5) Compressors

DC Series Motor:

- In this type of DC motor the armature and field windings are connected in series.
- the resistance of the series field winding Rs is much smaller than the armature resistance Ra



- The flux produced is proportional to the field current but in this $I_{f=}I_a$ thus $\emptyset \propto Ia$
- Thus flux can never become constant in dc series motor as load changes $\mathrm{I_f}$ and $\mathrm{I_a}$ also gets changed
- Thus dc series motor is not a constant flux motor.

Torque and Speed equation of DC Series Motor:

As we have seen for dc motor

$$T \propto \emptyset\, Ia$$

But for dc series motor as $I_{f=}I_a$ $thus\ \emptyset \propto Ia$

So torque in dc series motor is

$$T \propto Ia^2$$

For dc motor

$$Eb = \frac{N\emptyset ZP}{A60}$$

$Z\ , P, A\ and\ 60$ are constants

Thus,$N \propto \frac{Eb}{\emptyset} \propto \frac{(V-IaRa)-I_sR_s}{\emptyset} = \frac{V-Ia(Ra+R_s)}{\emptyset}$....... as Ia=I_s

for dc series motor

Characteristics of DC Series Motor:

To study the performance of the DC series Motor various types of characteristics are to be studied.

1. Torque Vs Armature current characteristics.
2. Speed Vs Armature current characteristics.
3. Speed Vs Torque characteristics

Torque Vs Armature current characteristics of DC Series motor

- Torque developed in any dc motor is

$$T \propto \emptyset Ia$$

- In case of a D.C. series motor, as field current is equal to armature current, and for small value of I_a

$$\emptyset \propto I_a$$

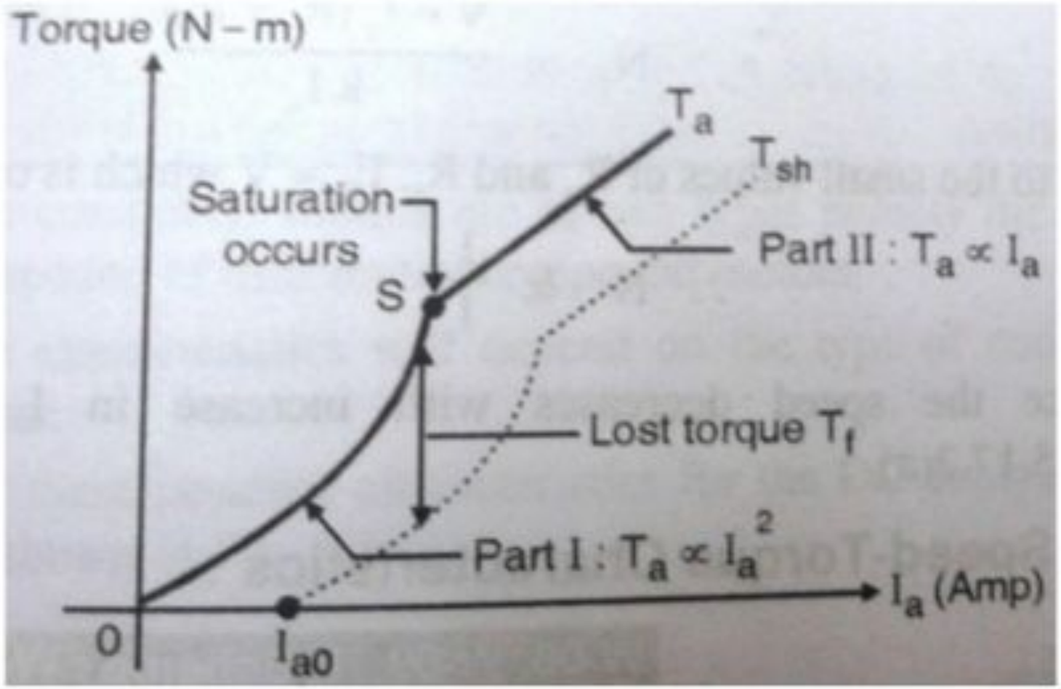
- Therefore the torque in the dc series motor for small value of I_a

$$T \propto Ia^2$$

- When I_a is large the $\emptyset$ remains the constant due to saturation, thus torque is directly proportional to armature current for large value of I_a

$$T \propto I_a$$

- Thus Torque Vs Armature current characteristics begin to raise parabolically at low value of armature current and when saturation is reached it become a straight line as shown below.



In DC series motors, (prior to magnetic saturation) torque increases as the square of armature current, these motors are used where high starting torque is required.

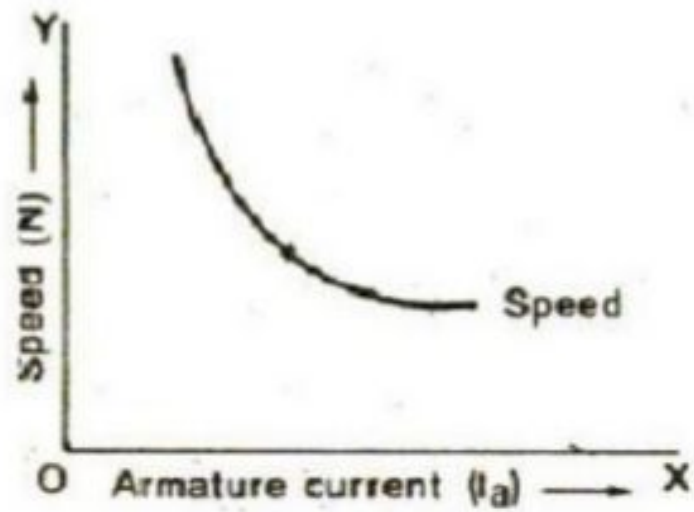
Speed Vs Armature current characteristics of DC Series Motor

Consider the following equation:

$$N = \frac{K(V - IaRa)}{\emptyset}$$

When supply voltage V is kept constant, speed of the motor will be inversely proportional to flux. In dc series motor field exciting current is equal to armature current which is nothing but a load current. Therefore at light load when saturation is not attained, flux will be proportional to the armature current and hence speed will be inversely proportional to armature current. Hence speed and armature current characteristics is hyperbolic curve upto saturation.

- As the load increases the armature current increases and field gets saturated, once the field gets saturated flux will become constant irrespective of increases in the armature current. Therefore at heavy load the speed of the dc series motor remains constant.
- This type of dc series motor has high starting torque.

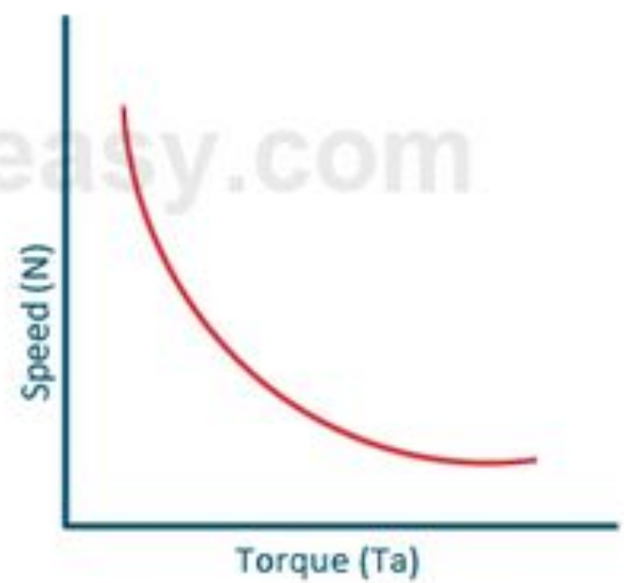


We know the relation, $N \propto Eb/\phi$. For small load current (and hence for small armature current) change in back emf (Eb) is small and it may be neglected. Hence, for small currents speed is inversely proportional to ϕ. As we know, flux is directly proportional to Ia, speed N is inversely proportional to Ia. Therefore, when armature current is very small the speed becomes dangerously high. That is **why a series motor should never be started without some mechanical load**.

But, at heavy loads, armature current Ia is large. And hence, speed is low which results in decreased back emf Eb. Due to decreased Eb, more armature current is allowed.

Speed Vs Torque characteristics of DC Series motor

- The Speed Vs Torque characteristics of dc series motor will be similar to the Speed Vs Armature current characteristics it will be rectangular hyperbola, as shown in the fig.



Applications of DC series Motor-

These motors are useful in applications where starti torque required is high and quick acceleration. Like:

1) Traction
2) Hoists and Lifts
3) Crane
4) Rolling mills
5) Conveyors

Characteristics Of DC Compound Motor

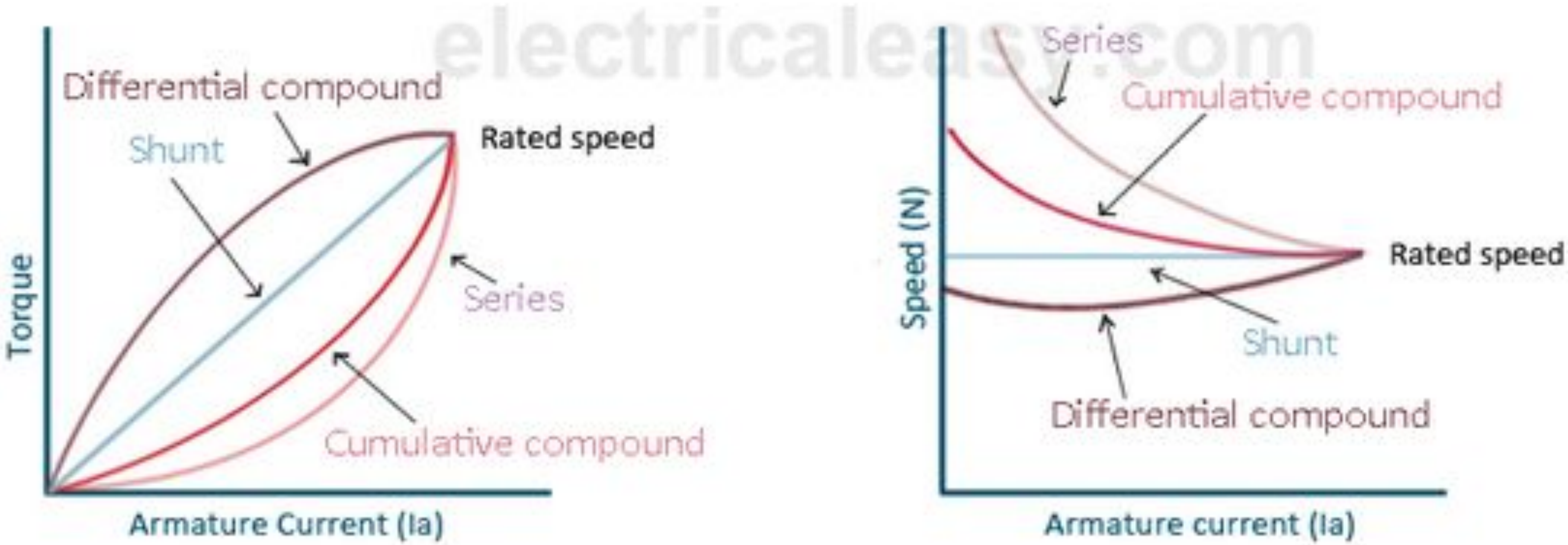
DC compound motors have both series as well as shunt winding. In a compound motor, if series and shunt windings are connected such that series flux is in direction as that of the shunt flux then the motor is said to be cumulatively compounded. And if the series flux is opposite to the direction of the shunt flux, then the motor is said to be differentially compounded. Characteristics of both these compound motors are explained below.

(a) Cumulative compound motor

Cumulative compound motors are used where series characteristics are required but the load is likely to be removed completely. Series winding takes care of the heavy load, whereas the shunt winding prevents the motor from running at dangerously high speed when the load is suddenly removed. These motors have generally employed a flywheel, where sudden and temporary loads are applied like in rolling mills.

(b) Differential compound motor

Since in differential field motors, series flux opposes shunt flux, the total flux decreases with increase in load. Due to this, the speed remains almost constant or even it may increase slightly with increase in load ($N \propto E_b/\phi$). Differential compound motors are not commonly used, but they find limited applications in experimental and research work.



Characteristics of DC compound motor

Applications of DC Compound Motor:

Cumulative Compound Motor:

- These motors have high starting torque.
- They can be operated even at no loads as they run at a moderately high speed at no load.
- Hence cumulative compound motors are used for the following applications.

1. Elevators
2. Rolling mills
3. Punches
4. Shears
5. planers

Need of Starter:

We know that, $V = E_b + I_a R_a$............for a dc shunt motor

and $V = E_b + I_a(R_a + R_s)$....for a dc series motor

Hence the expression for I_a are as follows:

$$I_a = \frac{V - E_b}{R_a} \text{...................... for dc shunt motor}$$

$$I_a = \frac{V - E_b}{(R_a + R_s)} \text{..................for dc series motor}$$

At the time of starting the motor, speed N=0 and hence the back emf E_b=0. Hence the armature current at the time of starting is given by,

$$I_{a(starting)} = \frac{V}{R_a} \text{............for dc shunt motor}$$

$$I_{a(starting)} = \frac{V}{(R_a + R_s)} \text{......for dc series motor}$$

- Since the the values of R_a and $R_s$are small, the starting currents will be tremendously large if the rated voltage is applied at the time of starting.
- The starting current of the motor can be 15 to 20 times higher than the full load current.
- Due to high starting current the supply voltage will fluctuate.
- Due to excessive current, the insulation of the armature winding may burn.
- The fuses will blow and circuit breakers will trip.
- For dc series motors the torque $\mathrm{T} \propto {I_a}^2$. So an excessive large starting torque is produced. This can put a heavy mechanical stress on the winding and shaft of the motor resulting in the mechanical damage to the motor.
- So to avoid all these effects we have to keep the starting current of motor below safe limit. This is achieved by using starter.

What would happen if a DC motor was supplied with AC and vice-versa?

1) In case of *Series connection of armature winding and field winding* , it may run.

2) But, In case of parallel connection , it won't rotate at all and will *start humming* and *will create vibrations,* as a *torque produced by positive and negative cycle will cancel out each other*. D.C. motor will be *heated up*.