Magnetic effect of Electric current

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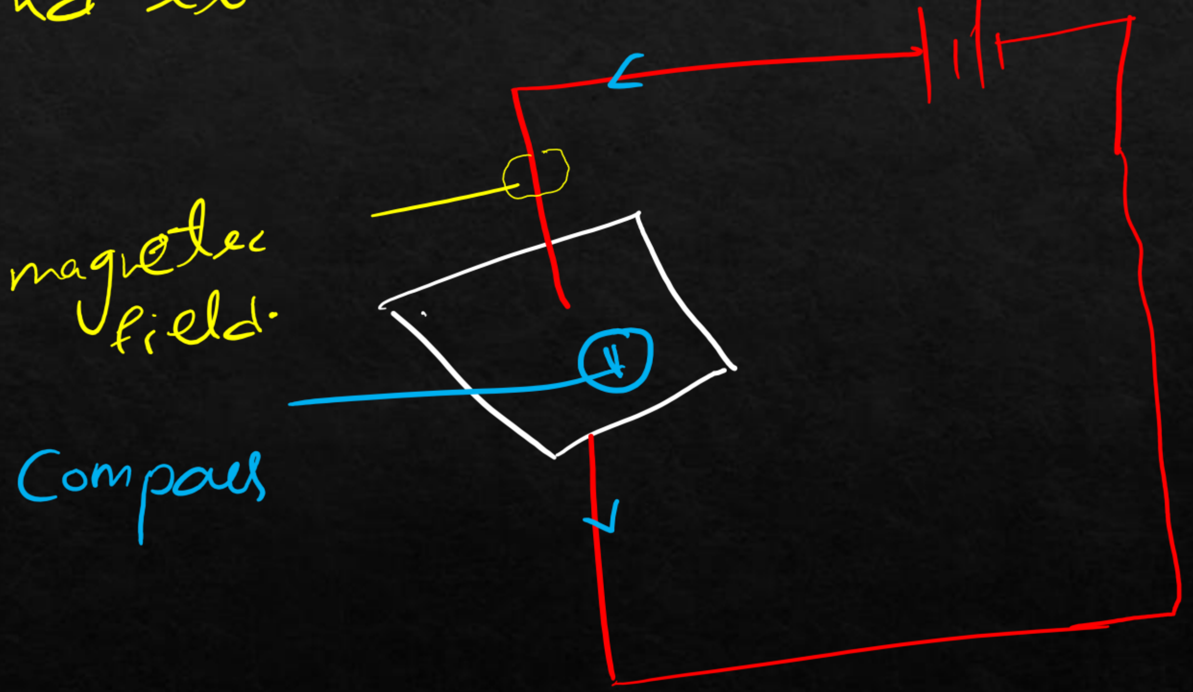
Magnetic effect of Electric current

Electric current through a metallic conductor produces a magnetic field around it.

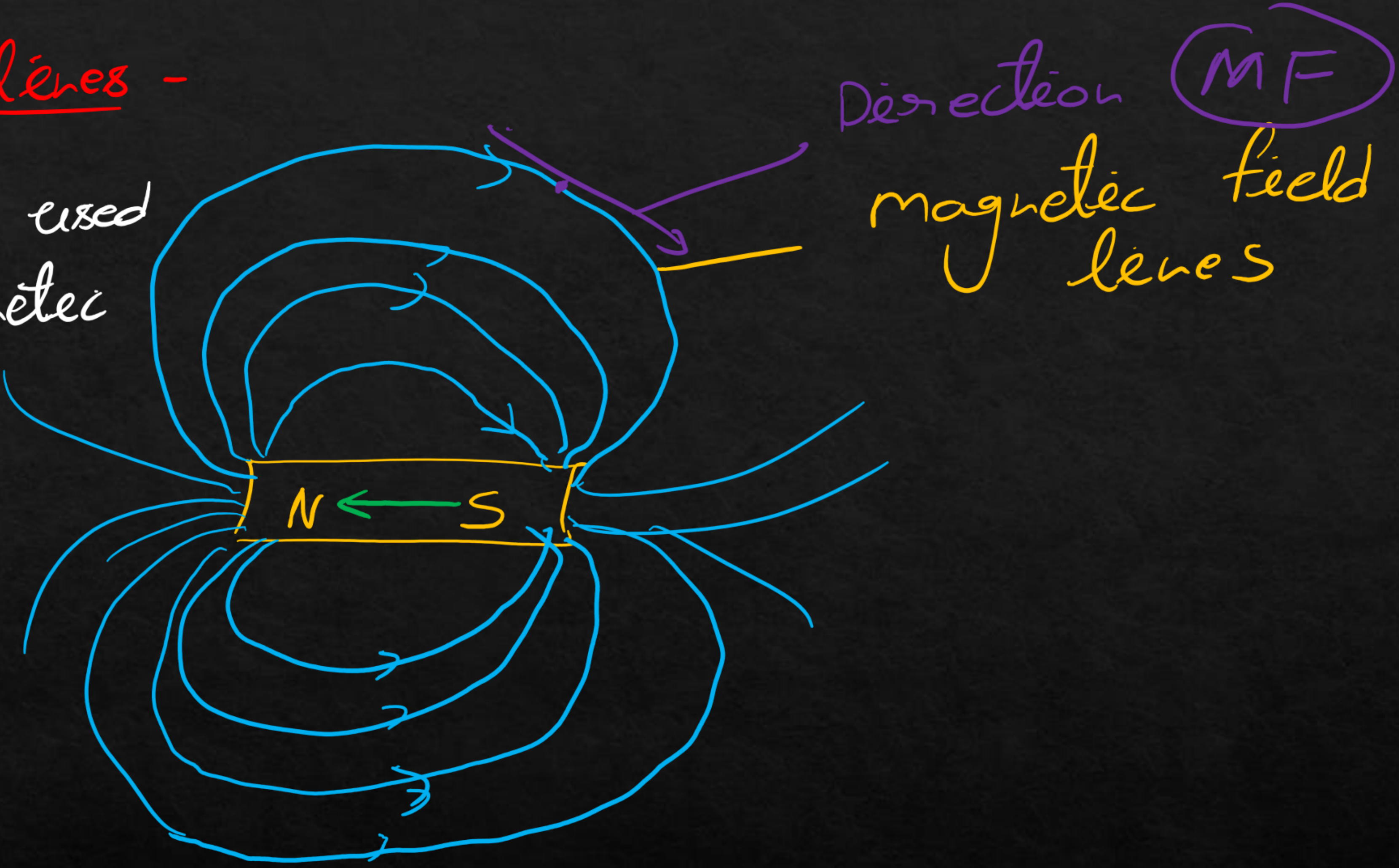
Magnetic field.

→ Space surrounding a magnet within a magnetic force is experienced.



Magnetic field lines -

↳ Imaginary lines used to represent magnetic field.



① Originate from North pole and end its south pole. but inside the magnet its from south to north.

② - They are contenous and formes closed curves.

③ - Tangent at any point on magnetic field lines gives the direction of magnetic field.

④ - Magnetic field lines never intersect eachother.

⑤ - If field lines are $\boxed{\text{close}}$, field is stronger. In field lines $\boxed{\text{apart}}$, field weak.

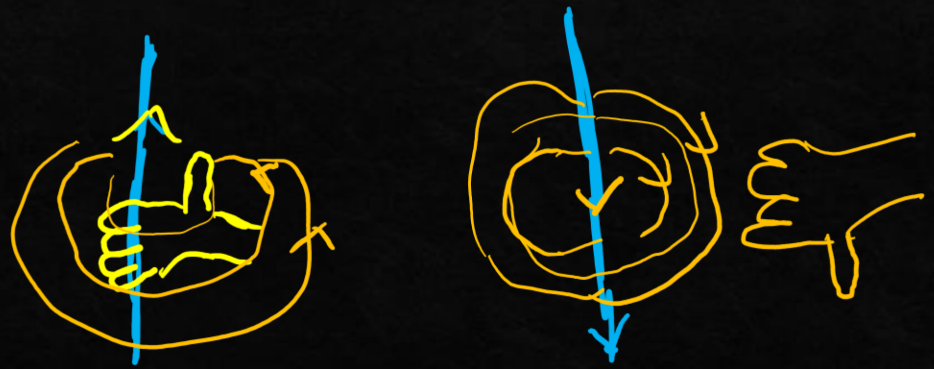
Magnetic field due to a current through a straight conductor-

↳ MF lines are concentric rings with centre at wire.

↳ Magnitude of magnetic field increases if current increased.

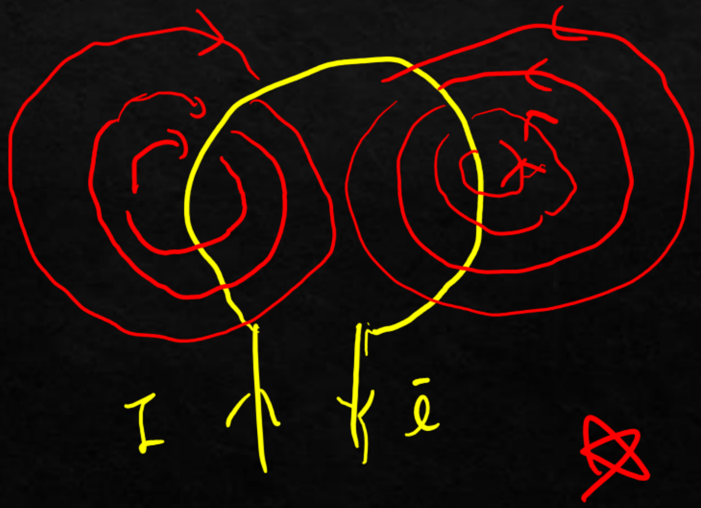
☆ Maxwell's Right hand thumb Rule-

If you hold the current carrying conductor in the grip of your Right hand in



Such way that streched thumb in direction of current, then curl of fingers will gives the direction of magnetic field.

Magnetic field due to a current through circular loop -



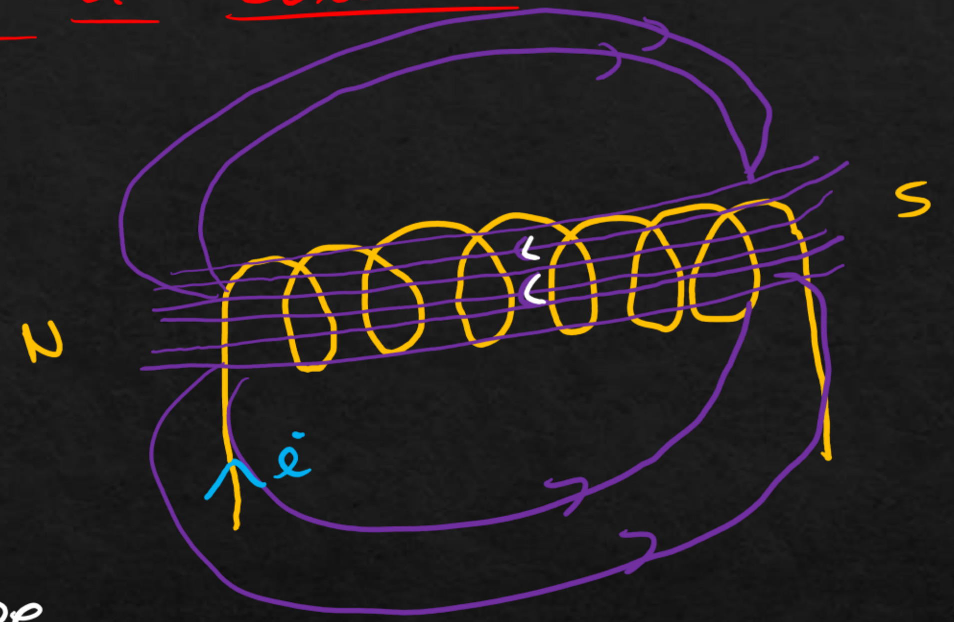
→ Strength of MF can also increase by increase no. of turns

→ Also by increasing the current.

MF due to current in a Solenoid -

Solenoid

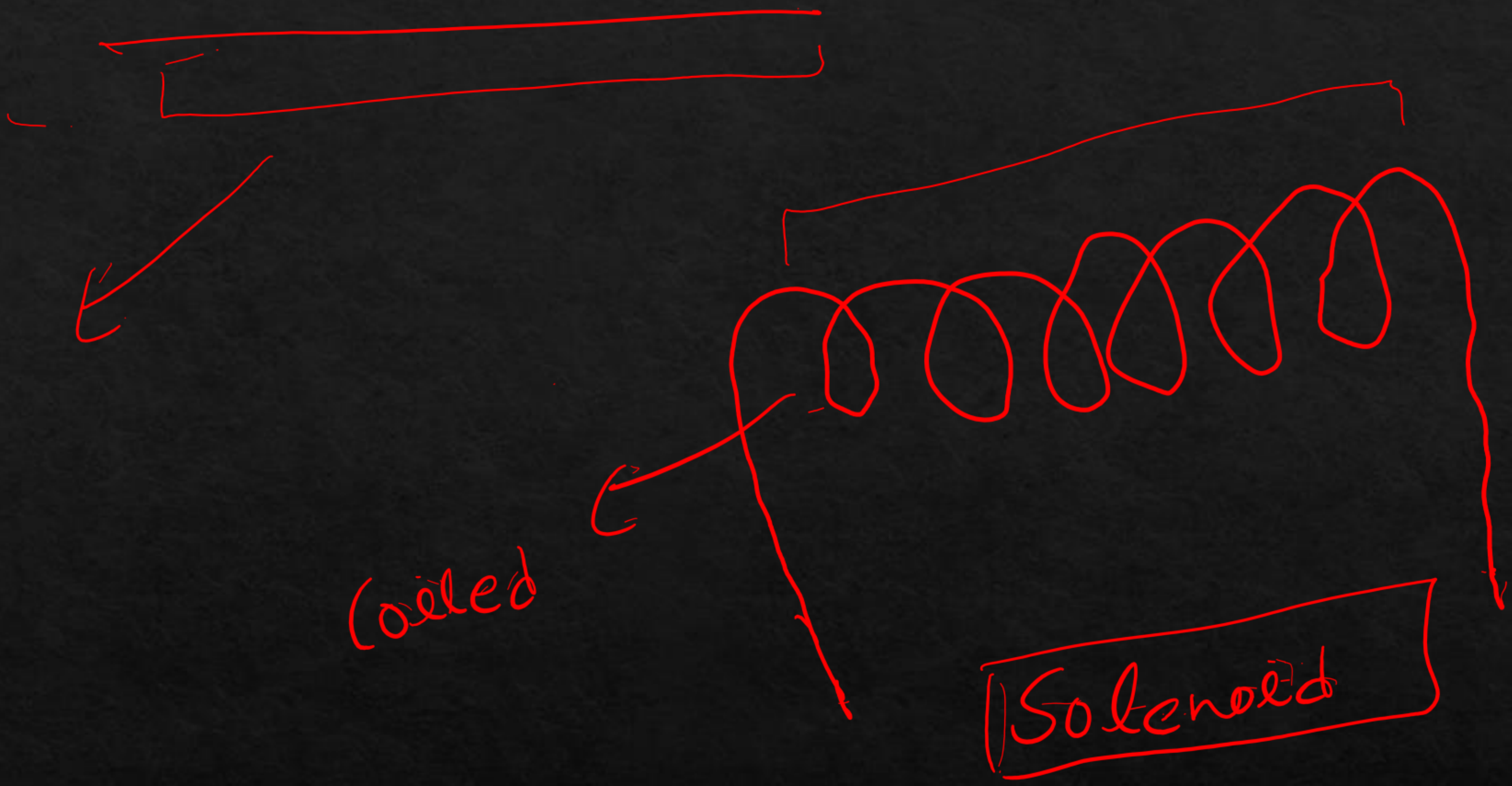
A coil of many circular turns of insulated copper wire wrapped closely in shape cylinder.



Solenoid.

☆ Same as in loop.

loop



Electromagnet

I shape

U shape

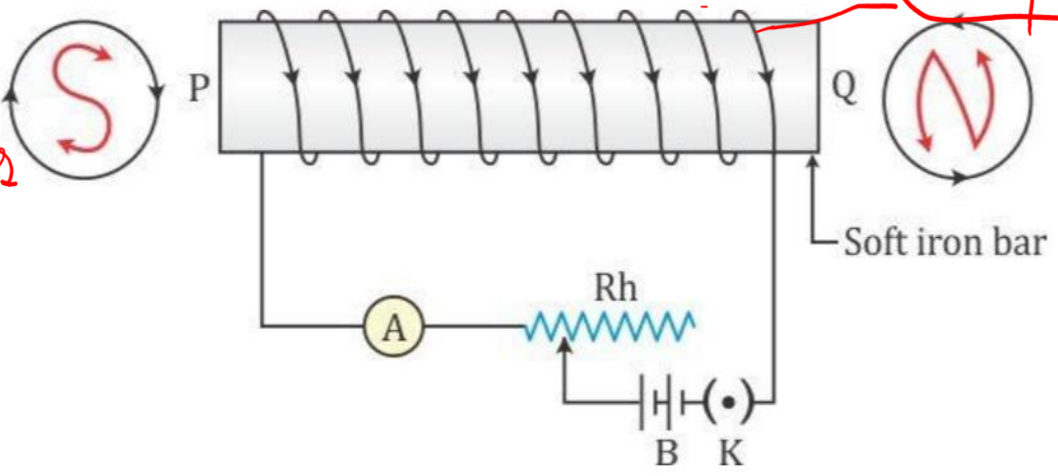
- An electromagnet is a temporary strong magnet made of a piece of soft iron when current flows in the coil wound around it. It is an artificial magnet.

(a) I-shaped electromagnet (or bar magnet)

- An I-shaped electromagnet is constructed by winding a thin insulated copper wire in the form of a solenoid around a straight soft iron bar. The ends of the wire are connected to a battery through an ammeter, rheostat and key.

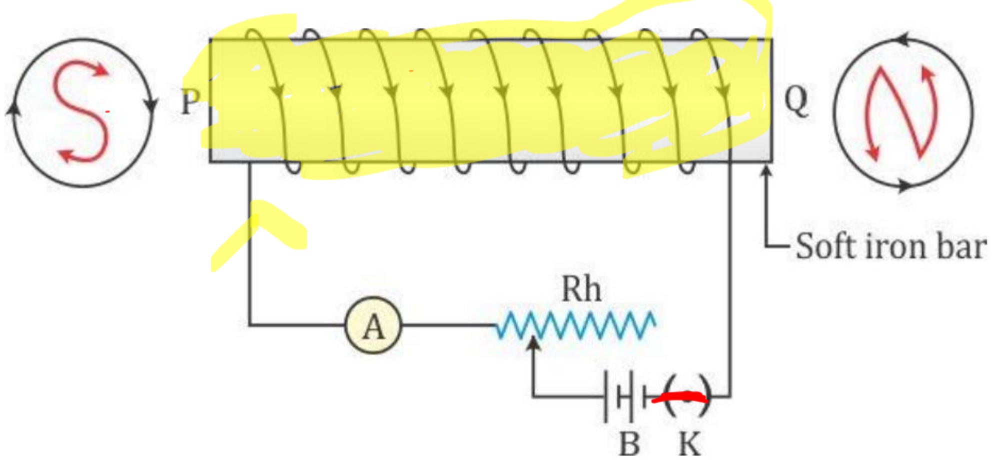
Copper wire.

Resistor



Clockwise → South

Anticlock

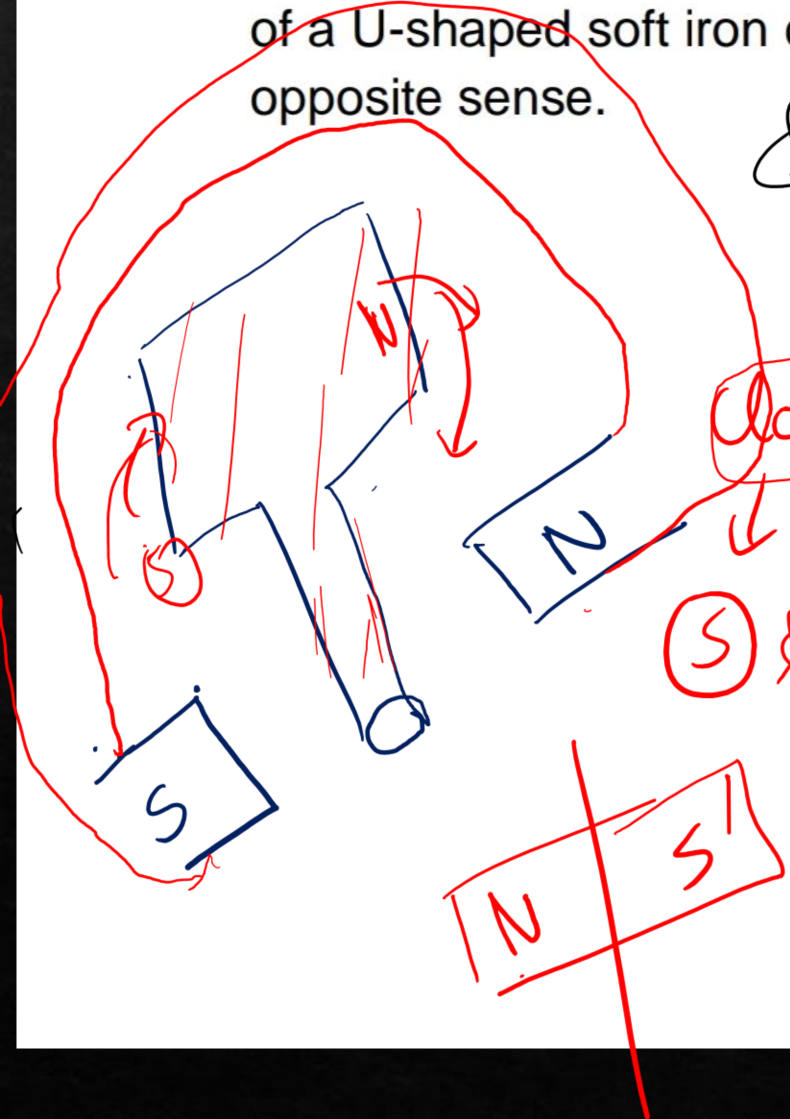


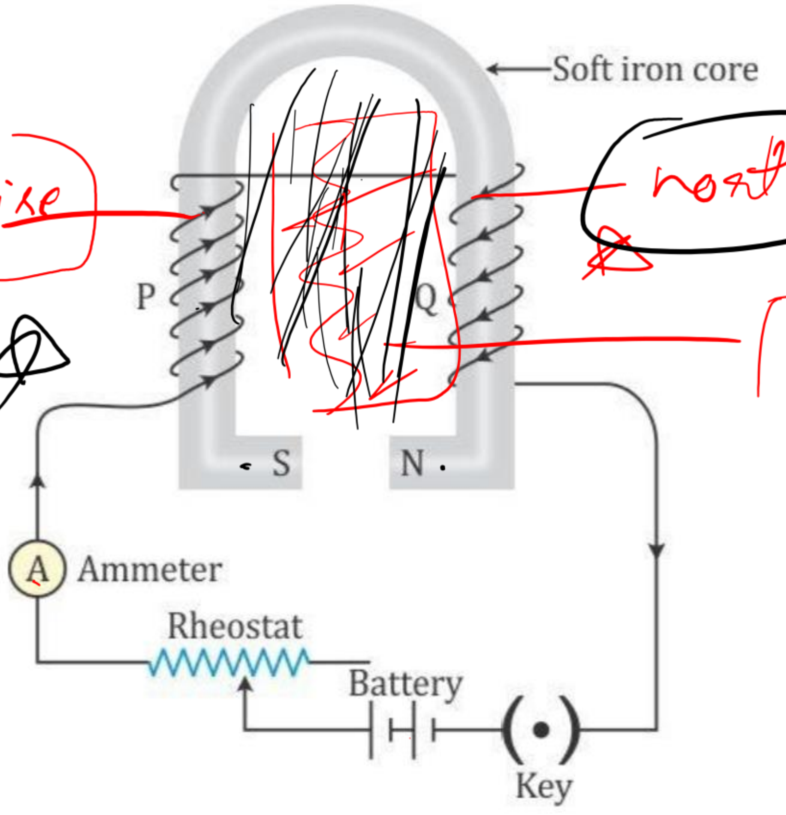
12 3 4 → S

- When current is passed through the winding of a solenoid by closing the key, one end of the bar becomes the South Pole (S) because the current at this face is clockwise, while the other end at which the current is anticlockwise becomes the North Pole (N).
- The soft iron bar acquires magnetic properties only when an electric current flows through the solenoid and loses magnetic properties when the current is switched off; thus, it is a temporary magnet. Such magnets are commonly used in a relay.

(b) U-shaped (or horseshoe) electromagnet

- To construct a horseshoe electromagnet, a thin insulated copper wire is spirally wound on the arms of a U-shaped soft iron core, such that the winding on the two arms as seen from the ends is in the opposite sense.





Clockwise

S

north

(anticlock)

DC

AC

N S

N S

- When current is passed through the winding by closing the key, one end of the arm becomes the South Pole (S) as the current at this face is clockwise, and the other end of the arm becomes the North Pole (N) as the current at this face is anticlockwise.
- Thus, we get a very strong magnetic field in the gap between the two poles. The magnetic field in the gap vanishes as the current in the circuit is switched off. It is also a temporary magnet. Such magnets are used in a DC motor, AC generator etc.

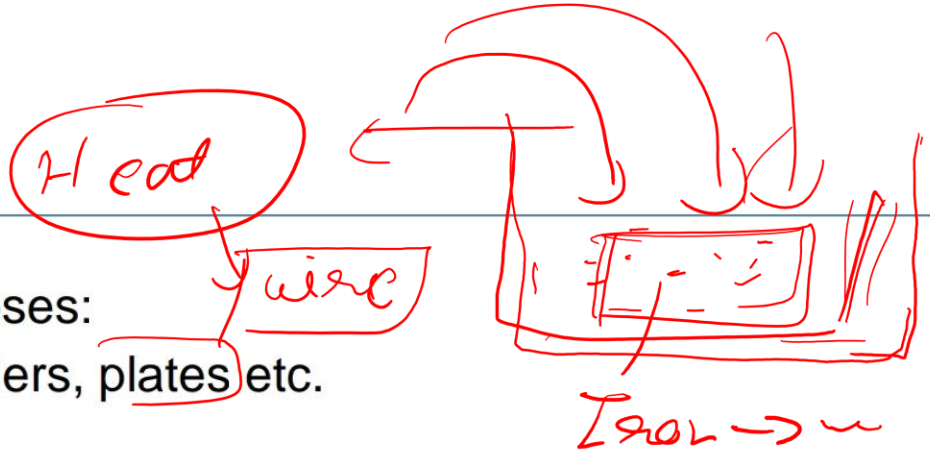
Ways of increasing the magnetic field of an electromagnet

- The magnetic field of an electromagnet (I- or U-shaped) can be increased by the following two ways:
  - By increasing the number of turns of winding in the solenoid
  - By increasing the current through the solenoid

Relay

Electronic Devic

Uses of Electromagnets



Electromagnets are mainly used for the following purposes:

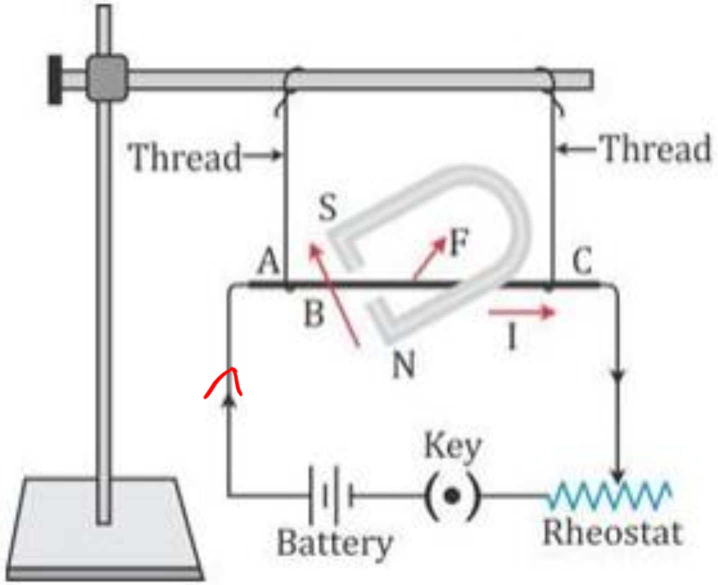
- To lift and transport large masses of iron scrap, girders, plates etc.
- To load furnaces with iron.
- To separate magnetic substances such as iron from debris and raw materials.
- To remove pieces of iron from wounds.
- In several electrical devices such as electric bell, telegraph, electric tram, electric motor, relay, microphone, loud speaker etc.
- In scientific research, to study the magnetic properties of a substance in a magnetic field.

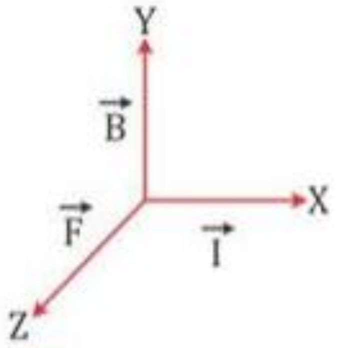
Permanent Magnet

- A permanent magnet is a naturally occurring magnet.
- A strong permanent magnet is made of steel instead of soft iron.
- These magnets are used in electric meters (e.g. galvanometer, ammeter, voltmeter) and in a magnetic compass etc.

Electromagnet	Permanent magnet
It produces a magnetic field as long as the current flows through its coils.	It produces a permanent magnetic field.
It is made of soft iron.	It is made of steel.
The magnetic field strength can be changed.	The magnetic field strength cannot be changed.
The polarity of an electromagnet can be reversed. S N N S	The polarity of an electromagnet cannot be reversed. N S
It can be easily demagnetised by switching off the current. X →	It cannot be easily demagnetised.

Force on a Current-carrying Conductor in a Magnetic Field





$\vec{I}$, $\vec{B}$ and $\vec{F}$ are mutually perpendicular to each other.

- When no current flows in the conductor, no force acts on the conductor and the conductor does not move. The wire is vertically below the support.
- When current is passed in the conductor, a force acts on the conductor in a direction perpendicular to both the direction of the current and the direction of the magnetic field.
- When the direction of the current through the conductor is reversed, the direction of force is also reversed.
- On reversing the direction of the magnetic field, the direction of force is reversed.
- When a conductor is placed such that the current in it is in the direction parallel to the direction of the magnetic field, no force acts on the conductor and it does not move.

Force → Current (i) → wire length → magnetic field (B) strength

Avg

Magnitude of force

- The magnitude of force acting on a current-carrying conductor placed in a magnetic field is found experimentally to depend on the following three factors:
  i. The force is directly proportional to the current I flowing in the conductor, i.e. $F \propto I$.
  ii. The force is directly proportional to the strength of the magnetic field B, i.e. $F \propto B$.
  iii. The force is directly proportional to the length l of the conductor, i.e. $F \propto l$.
  $F = IBl$
- The unit of magnetic field is given from the above equation as N A^{-1} m^{-1}.

$F \propto i$

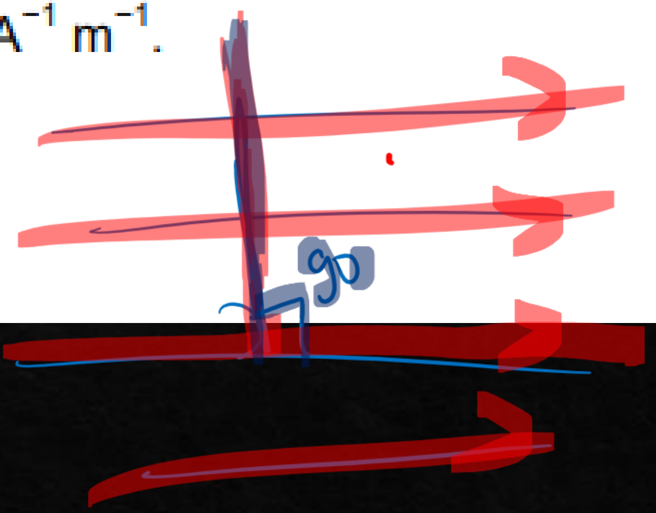
$F \propto l$

$F \propto B$

$F \propto iBl$

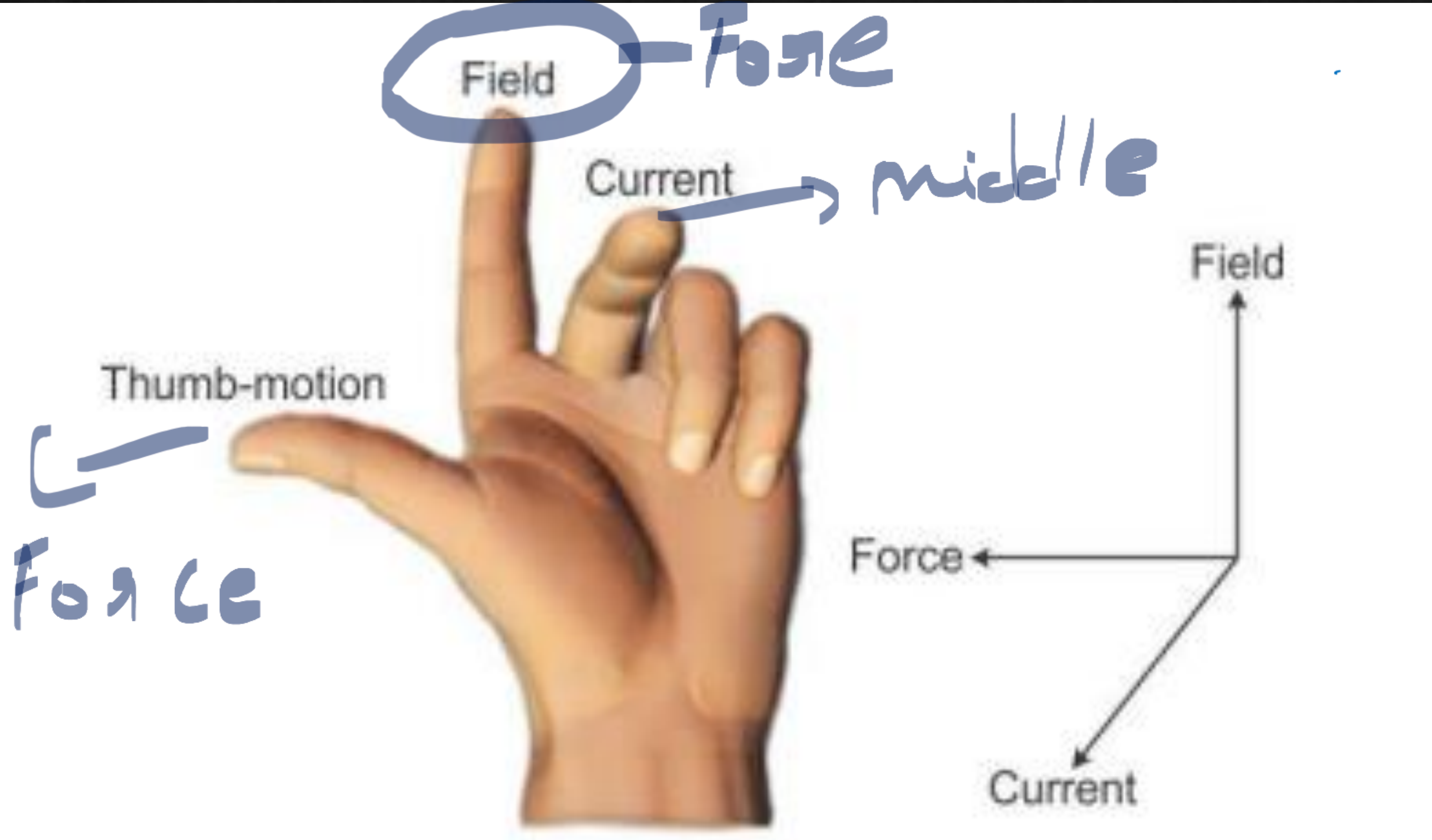
$\boxed{F = iBl\sin\theta}$

$F = iBL$



Direction of force: The direction of force on a current-carrying conductor placed in a magnetic field is obtained by the Fleming's left-hand rule.

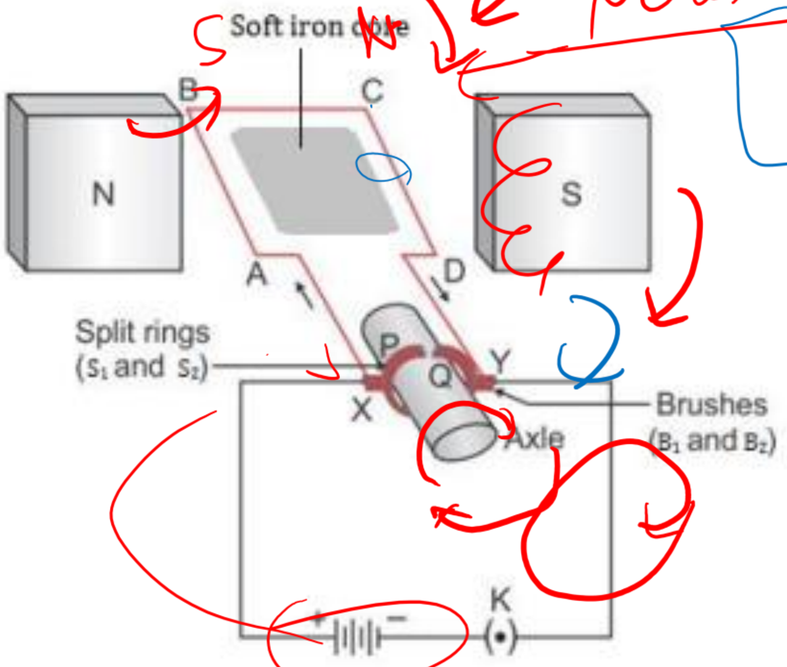
Fleming's left-hand rule: Stretch the forefinger, middle finger and thumb of your left hand mutually perpendicular to each other. If the forefinger indicates the direction of the magnetic field and the middle finger indicates the direction of the current, then the thumb will indicate the direction of motion of the conductor.



Simple DC Motor

- An electric motor is a device which converts electrical energy into mechanical energy.
- Principle: A DC motor works on the principle that when an electric current is passed through a conductor placed normally in a magnetic field, a force acts on the conductor as a result of which the conductor begins to move and mechanical energy (or work) is obtained. The direction of force is obtained by Fleming's left-hand rule.

Vertical



Area

electrical energy

mechanical → work

Ways of increasing the speed of rotation of a coil: The speed of rotation of a coil can be increased by $F \propto i$

i. Increasing the strength of the current in the coil
ii. Increasing the number of turns in the coil
iii. Increasing the area of the coil
iv. Increasing the strength of the magnetic field $F \propto B$

220 Battery → DC

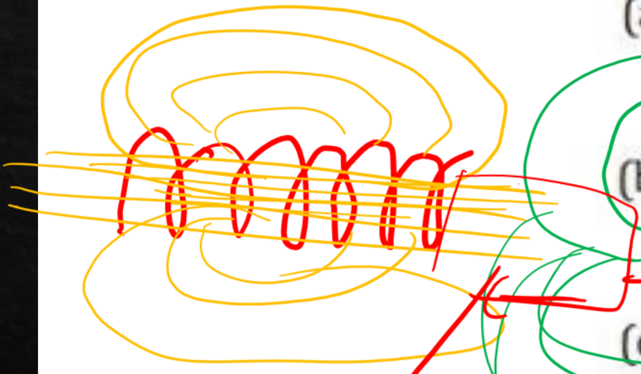
AC

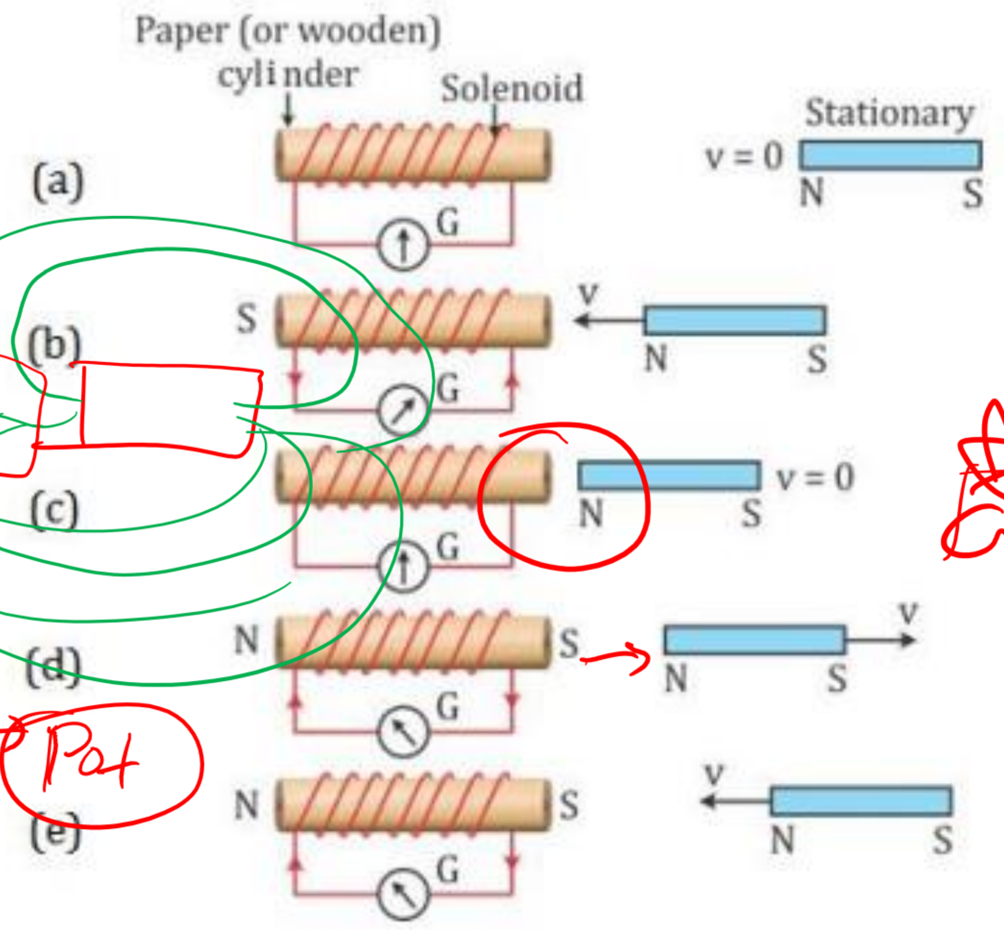
10A

Direction

Electromagnetic Induction

- Whenever there is a change in the number of magnetic field lines associated with a conductor, an electromotive force (emf) is developed between the ends of the conductor which lasts as long as the change is taking place. This phenomenon is called electromagnetic induction.



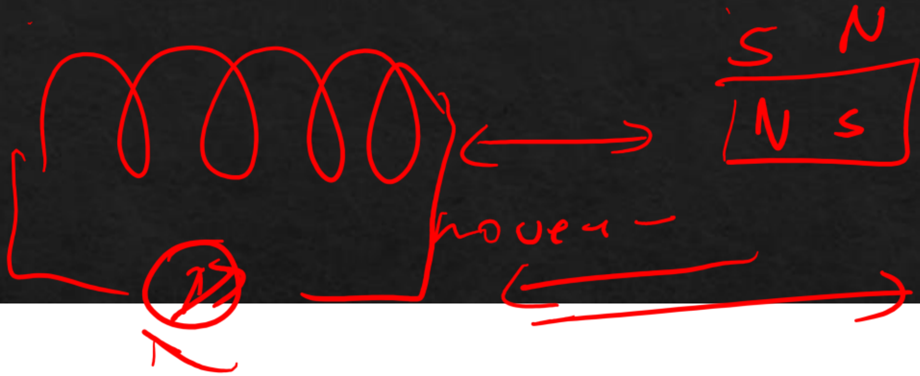


Generator

potential Difference (EMF)

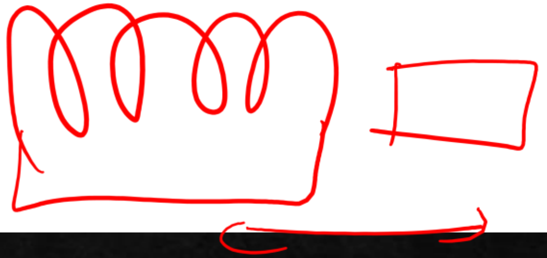
Strength → Pot

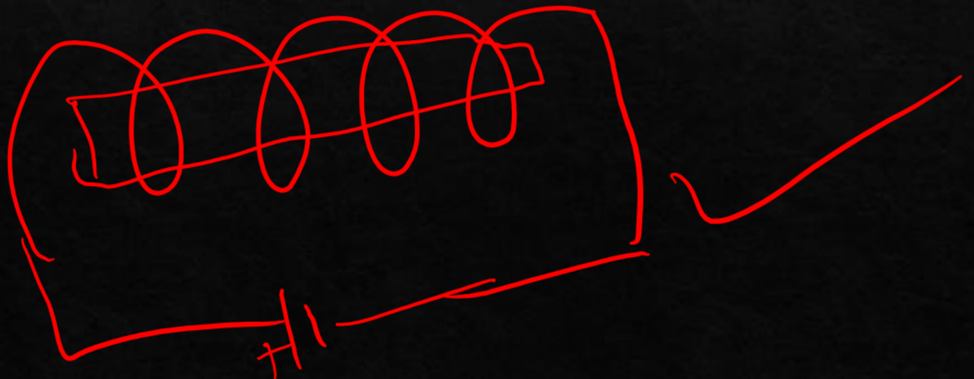
Increased Current



Conclusion

- A current flows in the coil only when there is a relative motion between the coil and the magnet due to which the galvanometer connected with the coil shows deflection.
- The direction of deflection in a galvanometer is reversed if the direction of motion (or polarity of the magnet) is reversed.
- The current in the coil is increased
  i. By the rapid motion of the magnet (or coil)
  ii. By using a strong magnet
  iii. By increasing the area and the number of turns in the coil





Faraday's Laws of Electromagnetic Induction

Uniform

2 km/h

i. Whenever there is a change in the magnetic flux linked with a coil, an emf is induced. The induced emf lasts as long as there is a change in the magnetic flux linked with the coil.

ii. The magnitude of the emf induced is directly proportional to the rate of change of the magnetic flux linked with the coil. When the rate of change of the magnetic flux remains uniform, a steady emf is induced.

Factors Affecting the Magnitude of Induced EMF

Induced EMF $\propto \frac{\Delta \phi}{\Delta T}$

The magnitude of induced emf is equal to the rate of change of magnetic flux, i.e.

$$\text{Induced e.m.f.} = \frac{\text{Change in magnetic flux}}{\text{Time in which the magnetic flux changes}} \quad \frac{\Delta \phi}{\Delta T}$$

Rate of change magnetic flux

Thus, for a given coil and magnet, emf depends on the following two factors:
(i) Change in the magnetic flux
(ii) Time in which the magnetic flux changes

Direction of Induced EMF

The direction of induced emf (and hence the direction of induced current) can be obtained by any of the following two rules:

- Fleming's right-hand rule: Stretch the thumb, middle finger and forefinger of your right hand mutually perpendicular to each other. If the forefinger indicates the direction of the magnetic field and the thumb indicates the direction of the motion of the conductor, then the middle finger will indicate the direction of the induced current.

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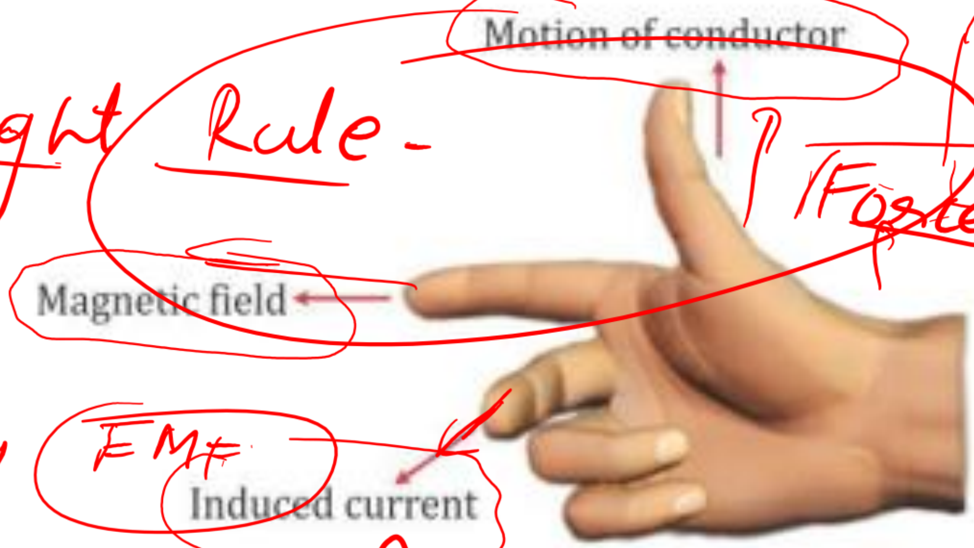
Fleming Right Rule-



Force

Faraday

$$\varepsilon = -N\frac{\Delta\phi}{\Delta T}$$

Changing magnetic flux

$\boxed{\text{Induce EMF}}$

opposi

EMF

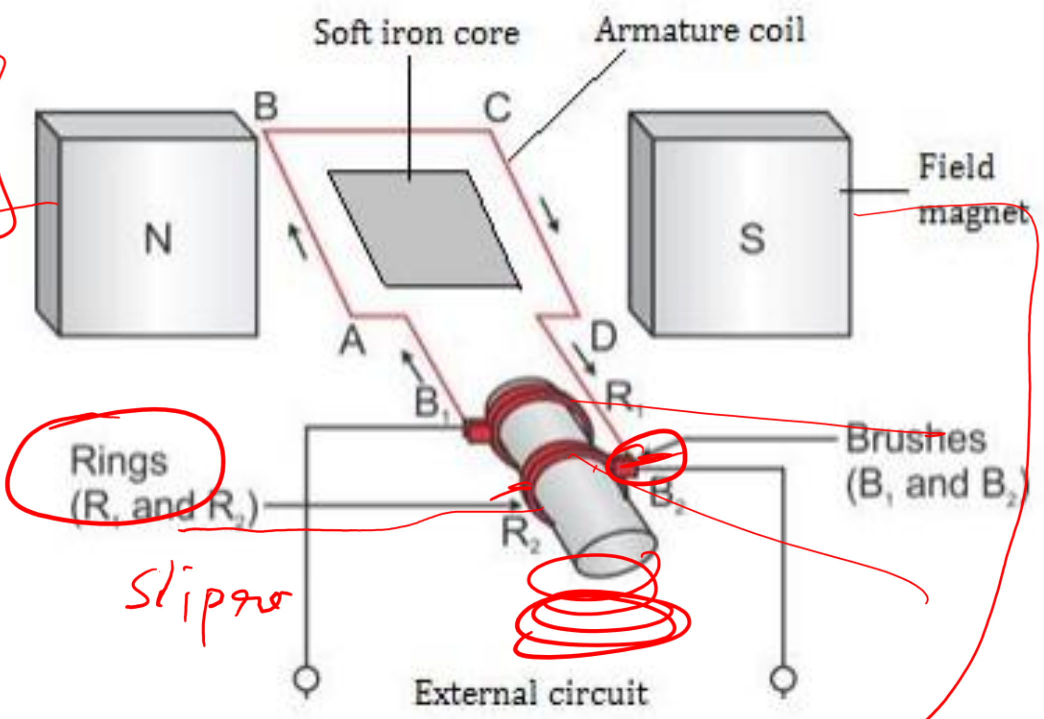
- Lenz's law: The direction of induced emf (or induced current) always tends to oppose the cause which produces it.

AC Generator

motor | Generator

- An AC generator is a device which converts mechanical energy into electrical energy using the principle of electromagnetic induction.
- In a generator, a coil is rotated in a magnetic field. Due to rotation, the magnetic flux linked with the coil changes and therefore an emf is induced between the ends of the coil. Thus, a generator acts like a source of current if an external circuit containing a load is connected between the ends of its coil.

F = eBlsenα

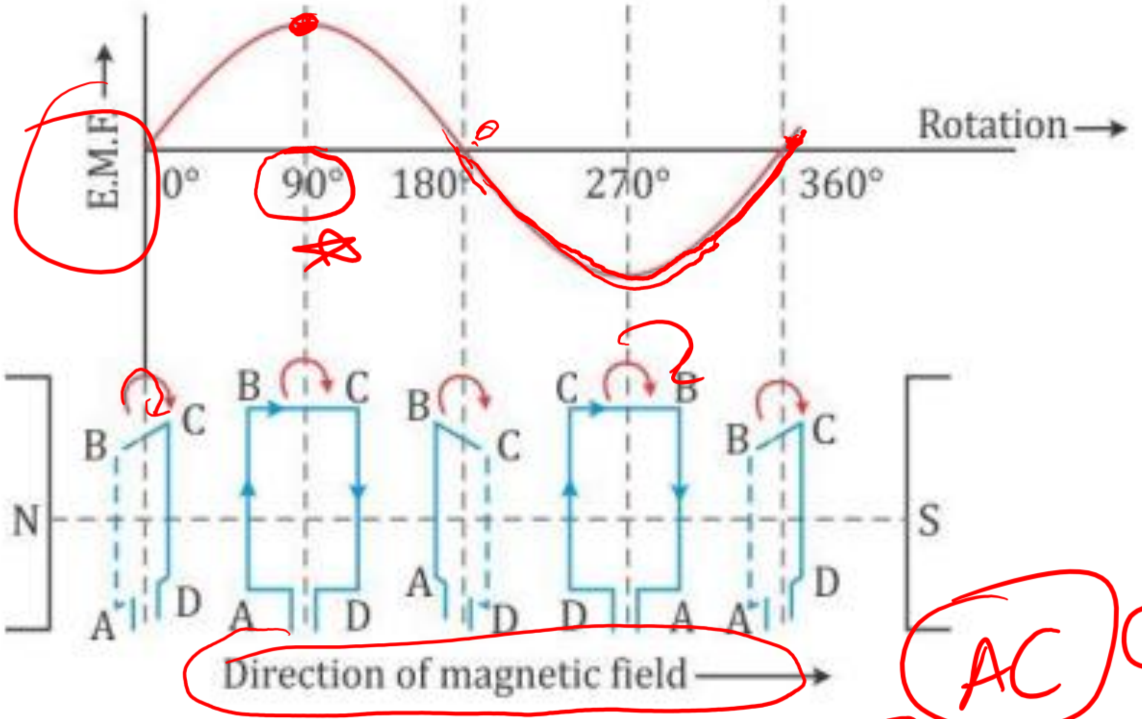


But

mechanical

Electrical Energy

- The figure below represents the emf induced between the ends of the coil with respect to the position of the coil in the magnetic field when seen along the axis of rotation from the position of slip rings.



AC $\propto$ rotation

Frequency of Alternating Current

- In one complete rotation of the coil, we get one cycle of alternating emf in the external circuit.
- The alternating emf thus produced has a frequency which is equal to the frequency of rotation of the coil.
- If the coil makes n rotations per second, then the magnitude of induced emf is given as

$$e = e_0 \sin 2\pi nt$$

and the current is expressed as

$$i = i_0 \sin 2\pi nt$$

emf

AC and DC

A current of constant magnitude and unique direction is called DC, while a current of changing magnitude and direction is called AC. A battery is a DC source, while an AC generator and the mains are AC sources.

Differences between AC and DC

Direct current (DC)	Alternating current (AC)
It is the current of constant magnitude.	It is the current of magnitude varying with time.
It flows in one direction in the circuit.	It reverses its direction while flowing in the circuit.
It is obtained from a cell (or battery).	It is obtained from an AC generator or the mains.

1000
2000

Advantages of AC over DC

high

- The use of AC is advantageous over DC because the voltage of AC can be stepped up by using a step-up transformer at the power generating station before transmitting it over long distances. This reduces the loss of electrical energy as heat in the transmission line wires.
- The AC is then stepped down to 220 volt by using step-down transformers at the successive sub-stations before supplying it to the houses or factories.
- If DC is generated at the power generating station, then its voltage cannot be increased for transmission. Due to the passage of high current in the transmission line wires, there will be a huge loss of electrical energy as heat in the line wires.

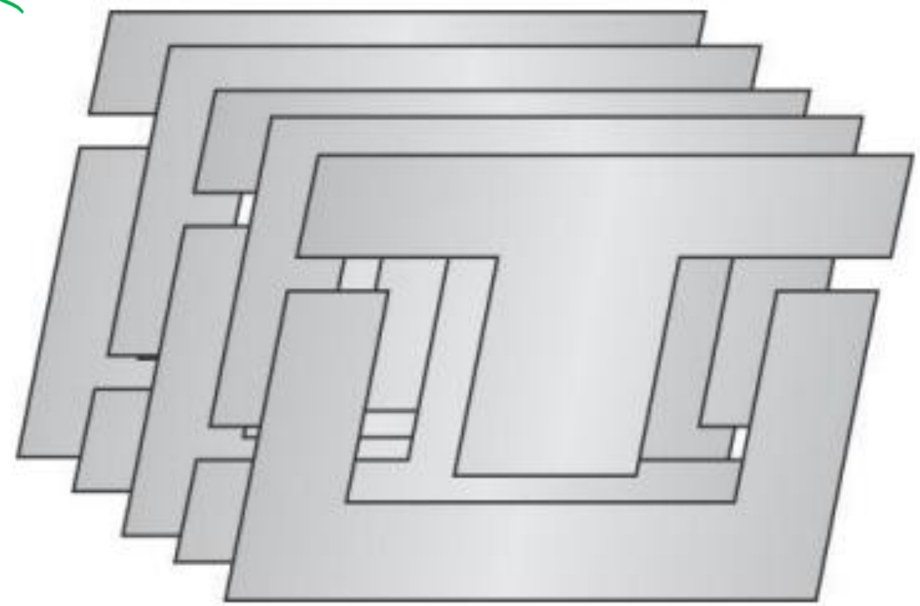
At stepped up

Distinction between an AC Generator and DC Motor

AC generator	DC motor
It is a device which converts mechanical energy into electrical energy.	It is a device which converts electrical energy into mechanical energy.
It works on the principle of electromagnetic induction.	It works on the principle of force acting on a current-carrying conductor placed in a magnetic field.
In a generator, the coil is rotated in a magnetic field to produce electric current.	In a DC motor, the current from the DC source flows in the coil placed in a magnetic field due to which the coil rotates.
It makes use of two separate coaxial slip rings.	It makes use of two parts of a slip ring which acts as a commutator.

Transformer

- A transformer is a device by which the amplitude of an alternating emf can be increased or decreased.
- A transformer does not affect the frequency of the alternating voltage. The frequency remains unchanged (= 50 Hz).
- A transformer works on the principle of electromagnetic induction and makes use of two coils. When there is a change of magnetic field lines due to varying current in one coil, an induced varying current of the same frequency flows in the other coil.
- A transformer cannot be used with a direct current (DC) source.



Input

output

Energy loss

Ideal

- The ratio of number of turns N_s in the secondary coil to the number of turns N_p in the primary coil (i.e. N_s/N_p) is called the turns ratio.

$$\text{Turns ratio} = n = \frac{\text{Number of turns in secondary coil } N_s}{\text{Number of turns in primary coil } N_p}$$

$$\boxed{\frac{N_s}{N_p} = n}$$

- The advantage of using a closed core is that it gives a closed path for the magnetic field lines and therefore almost all the magnetic field lines caused by the current in the primary coil remain linked with the secondary coil.
- When the terminals of the primary coil are connected to the source of alternating emf, a varying current flows through the primary coil. This varying current produces a varying magnetic field in the core of the transformer. Thus, the magnetic field lines linked with the secondary coil vary.
- The change of magnetic field lines through the secondary coil induces an emf in it. The induced emf varies in the same manner as the applied emf in the primary coil varies and thus has the same frequency as that of the applied emf.

For a transformer, we have

$$\frac{\text{E.m.f. across the secondary coil } E_s}{\text{E.m.f. across the primary coil } E_p} = \frac{\text{Number of turns in secondary coil } N_s}{\text{Number of turns in primary coil } N_p}$$

$$\frac{E_s}{E_p} = \frac{N_s}{N_p} = n$$

Ideal Transformer

$$\frac{E_s}{E_p} = \frac{N_s}{N_p}$$

For an ideal transformer, when there is no energy loss, the output power will be equal to the input power, that is

$$E_s I_s = E_p I_p$$

$$\underbrace{E_s I_s} = \underbrace{E_p I_p}$$

$N_s > N_p$

AC

factory

Types of Transformers

The two types of transformers are the step-up transformer and the step-down transformer.

- **Step-up transformer:** The transformer used to change a low voltage alternating emf to a high voltage alternating emf (of same frequency) is called a step-up transformer. In a step-up transformer, the number of turns in the secondary coil is more than the number of turns in the primary coil.
- **Step-down transformer:** The transformer used to change a high voltage alternating emf to a low voltage alternating emf (of same frequency) is called a step-down transformer. In a step-down transformer, the number of turns in the secondary coil is less than the number of turns in the primary coil.

high $\rightarrow$ low

AC

house

$N_s < N_p$

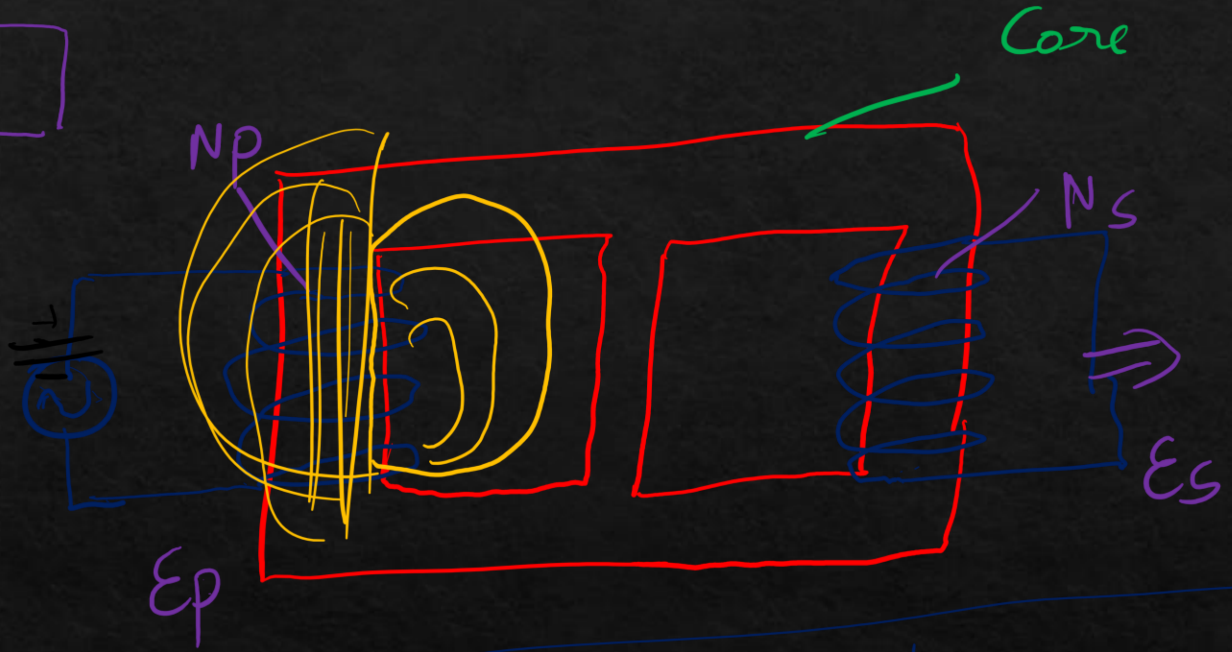
$$\boxed{\varepsilon = -N\frac{\Delta\Phi}{\Delta T}}$$

Transformer

$$\varepsilon_p = -N_p\frac{\Delta\phi}{\Delta T}$$

$$\varepsilon_s = -N_s\frac{\Delta\phi}{\Delta T}$$

$$\boxed{\frac{\varepsilon_s}{\varepsilon_p} = \frac{N_s}{N_p}}$$



$N_s > N_p$	Step up
$N_s < N_p$	Stepdown

North

2. The primary coil of a transformer has 800 turns and the secondary coil has 8 turns. It is connected to a 220 V a.c. supply. What will be the output voltage ?

Ans. 2·2 volt

$N_p = 800$

$N_s = 8$

$E_p = 220$

$$\boxed{\frac{E_p}{E_s} = \frac{N_p}{N_s}}$$

$$E_s = \frac{N_s \times E_s}{N_p} = \frac{\cancelto{1}{8} \times 22\cancel{0}}{\cancelto{10}{80\cancel{0}}}$$

$$E_s = \frac{22}{10} = 2.2\ v.$$

out put

3. A transformer is designed to give a supply of 8 V to ring a house-bell from the 240 V a.c. mains. The primary coil has 4800 turns. How many turns will be in the secondary coil ?

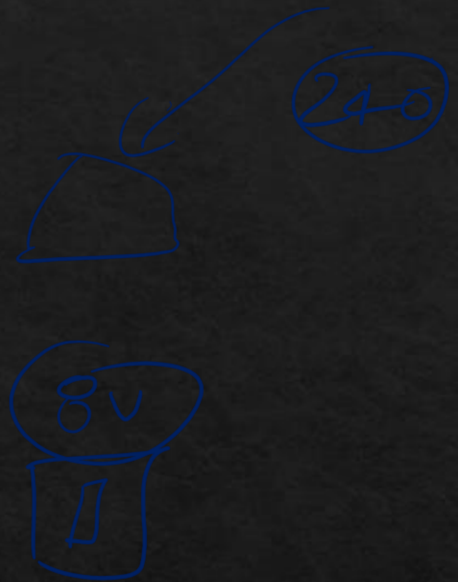
Ans. 160

$N_p = 4800$

$N_s = ?$

$E_s = 8v$

$E_p = 240$



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4. The input and output voltages of a transformer are 220 V and 44 V respectively. Find : (a) the turns ratio, (b) the current in input circuit if the output current is 2 A.

Ans. (a) 1 : 5 (b) 0·4 A

$E_p = 220\,V$

$E_s = 44\,V$

$\boxed{(i) - n = ?}$

$(ii) - I_s = 2A$

$I_s = ?$

$n = \frac{N_s}{N_p} = \frac{E_s}{E_p} = \frac{44}{220} = \boxed{1:5}$

$\boxed{E_s I_s = E_p I_p}$

$I_p = \frac{44 \times 2}{220} = \frac{\cancel{88}}{\cancel{220}_{110}} = \boxed{0.4}$

y you.
own ?
e kept
North

1. The magnetic flux through a coil having 100 turns decreases from 5 milli weber to zero in 5 second. Calculate the e.m.f. induced in the coil.

Ans. 100 mV

has 800 turns

Tesla

$N = 100$

$t = 5$ second