-A-

Ch6 : Electromagnetic Induction.

Broad Background (For Info.)

In 1820, Oersted ~~told~~ found "Electric charges in motion" (meaning current in a closed loop) produce "magnetic field"

This is supported by Ampere and Faraday. ~~They said~~. This is verified when the electric current deflects a magnetic compass needle placed in its vicinity.

Effects of moving charges (or effects of electric current)
- heating effect (electric heater, iron box) → Electrl energy → Heat energy
- Lighting effect (bulb) → Electrical energy → light energy
- Magnetic effect (fans, Mixers, motors), washing machine etc) → Electrical energy → Mechanical energy.

So, "Moving electric charges" produce "mag. fields", Is the converse effect possible → **YES**

"Moving Magnets" produce "electric currents".
Faraday / Henry demonstrated that electric currents were induced in closed conducting coils when subjected to changing magnetic fields.
Application : AC / DC generators

(See page B) →

The phenomenon in which electric current is generated by varying magnetic fields is called "Electromagnetic Induction".

Maxwell / Lorentz showed "interdepedence" of these two phenomena. This field is called Electromagnetism.

Mindmapping of electromagnetic induction.

— B — -Mind Mapping —

Moving Magnets produce Electric Currents :

→ Mechanical energy → Electrical energy →

(due to e-m induction (discovered by Faraday))

The mechanism of producing induced emf (and hence induced current in a closed circuit) due to change in magnetic flux linked with the closed circuit is known as Electromagnetic Induction.

Magnetic flux (ϕ_B) ~~is defined~~ through any surface is defined as the total number of magnetic field lines passing through that surface. $\phi_B = \vec{B} \cdot \vec{A} = BA\cos\theta$; where B = uniform magnetic field, A is the "⊥r to surface area" surface area and θ is angle between $\vec{B}$ and

Faraday's I Law : The magnitude of the induced emf in a circuit is equal to time rate of change of magnetic flux thro' the circuit

$$\boxed{\mathcal{E} = -N\frac{d\phi_B}{dt}}$$

N : No. of turns in the coil

II Law (Lenz's law) : "The direction of induced emf (or current in a closed circuit) in any circuit is such as to oppose the cause that produces it". (Faraday was aware of the direction, however Lenz stated it properly and hence 2nd law is called Lenz's law.

Direction of Induced emf → "Fleming's Right hand rule" shows the direction of induced current when a conductor moves in a magnetic field. (AC/DC Generators)

③ parameters (Fleming's RHR)

① ~~Indu~~ Magnetic field → (Fore finger)

② Force or motion → (thumb)

③ hence induced emf (or current) → (Middle finger)

Applications of e-m induction

- AC Generators
- DC Generators

clue to ~~rember~~ remember Fleming's RHR and LHR

Fleming's Right-hand rule (Generators) [Mechanical energy → Electrical energy]

Fleming's left-hand rule (Electric motors, fans, refrigerator etc..) [Electrical energy → Mechanical Energy]

-X- See page #6 to know which rule to be applied to a particular case

— C — Mind Mapping —

Effects of Moving charges (or Effects of Electric Current)

- Lighting effect (bulb) → Electrical energy → Light energy.
- Heating effect (electric heater, iron box) → Electrical energy → Heat energy
- Magnetic effect (fans, Mixers, Motorsets) → Electrical energy → Mechanical energy.

(Electrical Energy → Mechanical Energy)

- Electric current (or charges in motion) through a conductor produces a "magnetic field around it (proved via compass needle deflection)
- Magnetic field → Vector Quantity (Magnitude + Direction)
  - → Magnitude depends on the density of the "magnetic field lines". The magnitude is greater where the magnetic field lines are crowded (at the poles)
  - → Direction of mag. field at ~~to~~ a point (in the space around a magnet or a current carrying conductor) is taken to be the direction where the ~~noth~~ north pole of the compass needle points.
    - → By convention "mag. field lines" emerge from the North pole and merge at the South pole outside the magnet. Inside the magnet, the direction of "mag. field lines" will be S → N. Thus, the "magnetic Field Lines" are closed curves.

magnetic field due to a current-carrying conductor.

② parameters
- ↳ current
- ↳ Magnetic field

Direction of $\vec{B}$ using ③ Methods

① Right-hand Thumb rule : Thumb → direction of current
Fingers wrapping around conductor → Magnetic field

② Maxwell's Cork screw rule : Screw Moving direction → current
(Fixing a screw with a screw driver) Screw driver rotation direction → $\vec{B}$

③ Right hand palm rule #1 : Thumb → Direction of current
(See page ③) Fingers → $\vec{B}$ ⊥r drawn from palm (See page 3)

FORCE on a Current-carrying Conductor in a Magnetic Field

Here ③ parameters
Direction
- ↳ current
- ↳ Mag. field
- ↳ Force (Motion)

Fleming's Left Hand Rule shows the direction of motion of ~~conductor~~ current-carrying conductor in a magnetic field.

Fleming's LHR (Thumb, Fore finger, Middle finger all are mutually ⊥r to each other)
① Middle finger → Direction of current
② Fore finger → Direction of $\vec{B}$
③ Thumb → Direction of Motion

Right-hand palm rule #2
(See page ④)

Application of Magnetic effect due to electric current [Electrical energy → Mechanical energy]

Electric Motors (used in Fans, Refrigerators, mixers, washing machine, Computers, MP3 players, water pumps etc.)

Electromagnetic Induction.

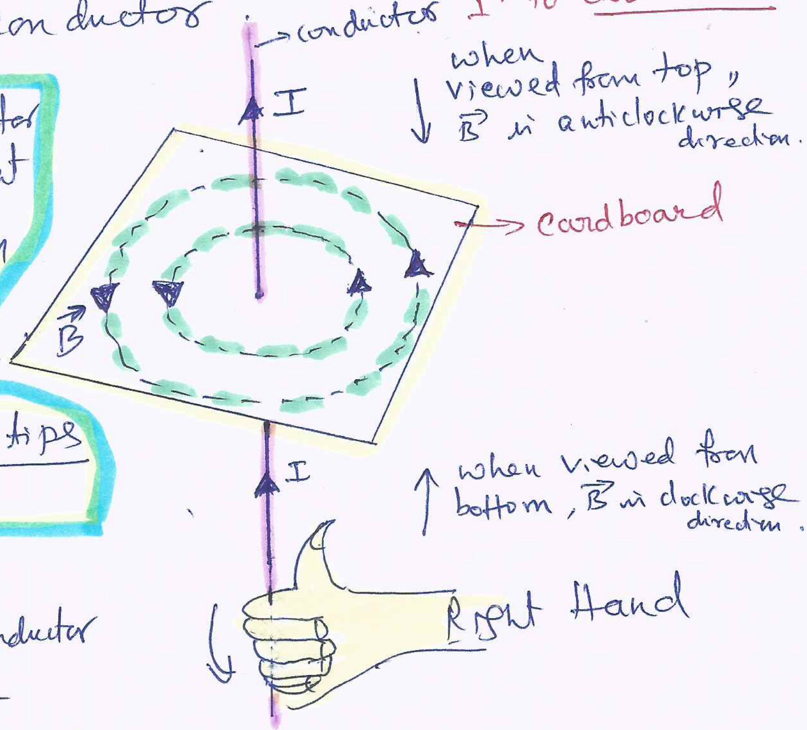
Before discussing "Electromagnetic Induction", we will discuss few rules that would give direction of magnetic field, current (or induced emf) and motion.

Direction of $\vec{B}$ due to current-carrying straight conductor

I Right Hand Thumb Rule

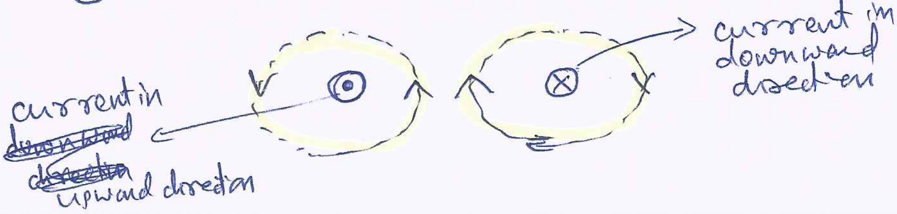
This rule is normally used to find the direction of magnetic field ($\vec{B}$) due to a straight current-carrying ~~current~~ conductor.

Rule ⟩ Grasp the st. conductor in our right hand such that thumb points in the direction of current, then the fingers curve in the direction of mag. field $\vec{B}$ with finger tips pointing along $\vec{B}$



The magnetic field around a current carrying straight conductor consists of concentric circles of magnetic ~~lines~~ field lines lying in a plane which is at right angles to the current carrying conductor.

→ The conventional sign for a magnetic field or current ⊥r to the plane of paper pointing upwards is denoted by dots ⊙. On the other hand, the magnetic field or current ⊥r to the plane of paper pointing downwards is denoted by ⊗ .. So above figure can be ~~drawn~~ represented as

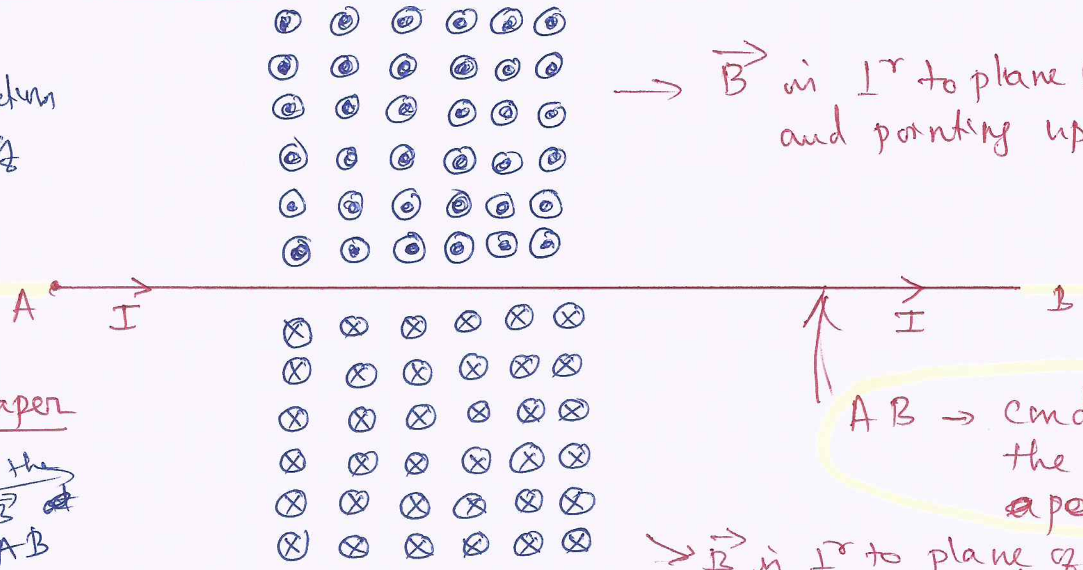


P.T.O.

When viewed from top

Contd. from ①

What is the direction of $\vec{B}$ on top of AB



Current I through Conductor AB on plane of paper

What is the direction of $\vec{B}$ below AB

→ $\vec{B}$ is $\perp^r$ to plane of paper and pointing upwards

AB → Conductor on the plane of paper.

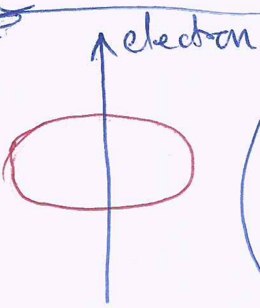
→ $\vec{B}$ is $\perp^r$ to plane of paper and pointing downwards.

~~When viewed from A~~

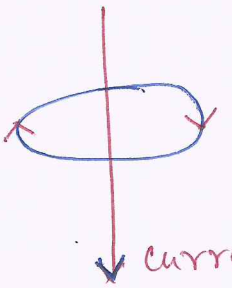
Tips: Instead of direction of current, if direction of electron is given, it is opposite to what we have discussed in page ① and ②.

Note: Direction of (Conventional) current is opposite to direction of electrons. All rules talk about direction of current (not electrons)

Ex 1

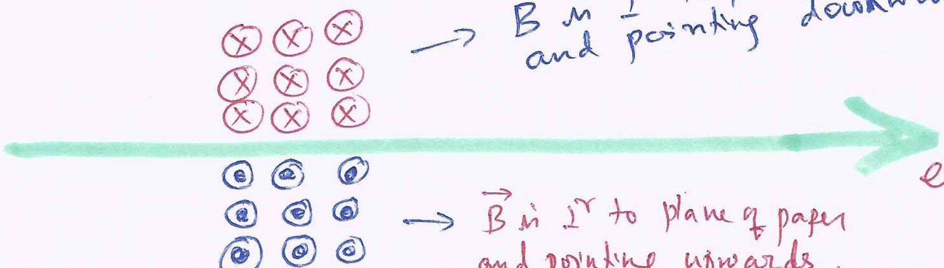


(take it like the As per RH Thumb rule)



Ex 2.

→ $\vec{B}$ is $\perp^r$ to plane of paper and pointing downwards



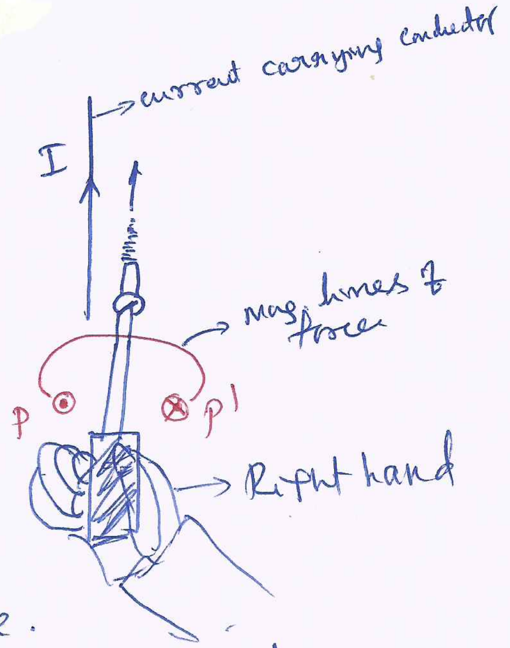
take conventional current opposite to electron current)

→ $\vec{B}$ is $\perp^r$ to plane of paper and pointing upwards.

P.T.O.

II Maxwell's Right hand Screw rule.

If we hold the screw-driver in the right hand and rotate it such that the screw moves in the direction of current in the conductor, then the direction of rotation of the thumb will be the direction of $\vec{B}$.



In fig, current carrying conductor is in the plane of the page and P and P' are points also in the plane of the page.

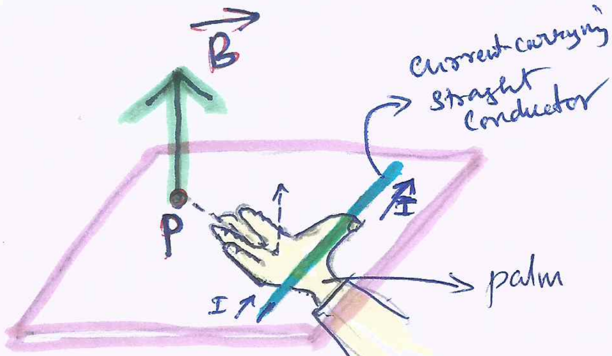
Applying this rule, $\vec{B}$ at P will be vertically upwards

and $\vec{B}$ at P' will be — " — downwards.

III Only to find direction of $\vec{B}$ due to current-carrying straight conductor

Right-hand palm rule 1 : This rule is only for

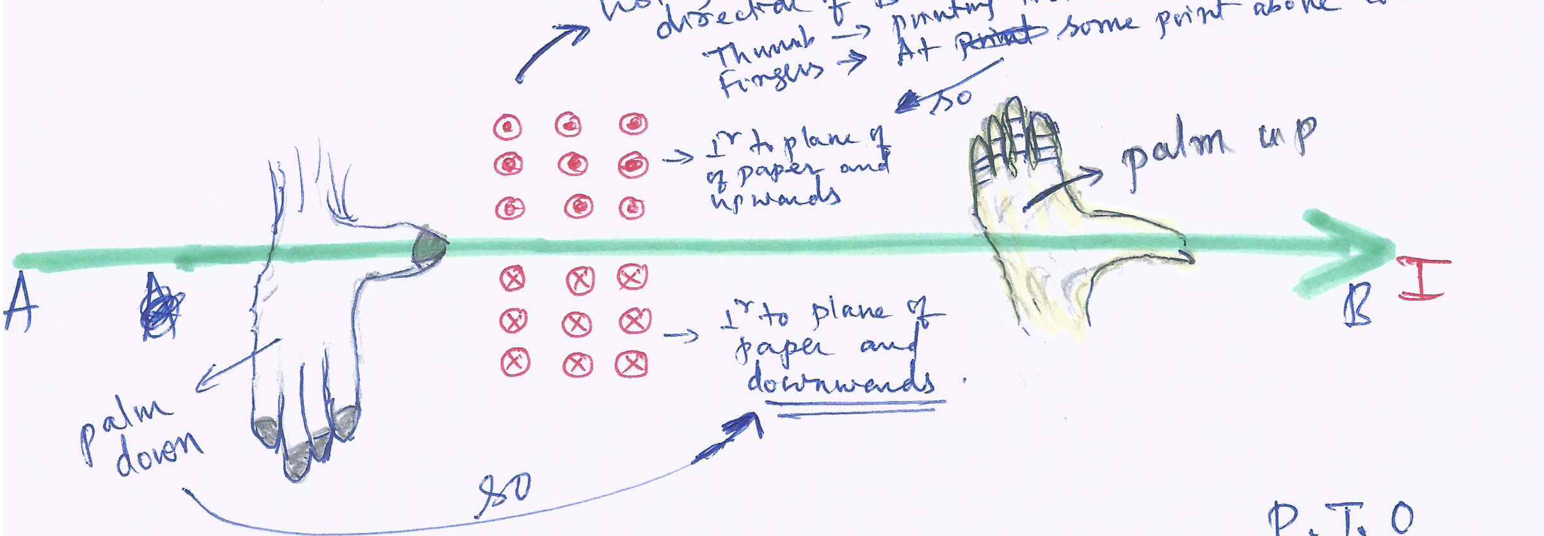
" If we stretch our right-hand palm such that the thumb points in the direction of current I and the fingers towards point P at which the direction of $\vec{B}$ is to be determined, then the $\perp^r$ drawn from the palm will give the direction of $\vec{B}$.



Using palm rule #1, we can easily determine direction of $\vec{B}$

Thumb → pointing in the direction of current

Fingers → At some point above conductor AB

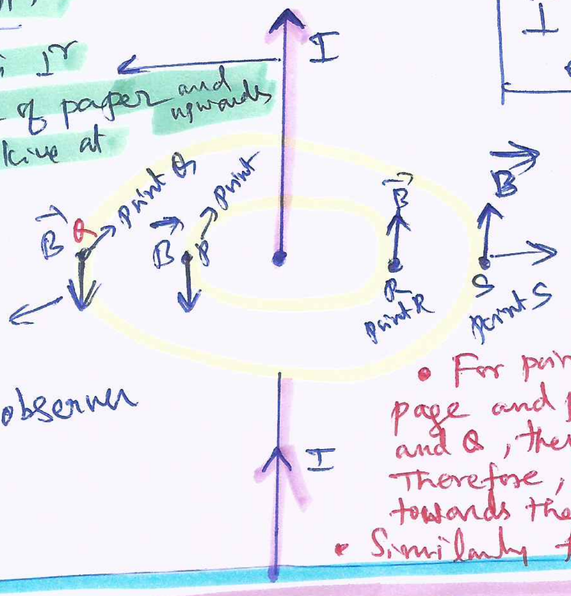


Using palm Rule #1

- If I is $\perp^r$ to plane of paper and upwards
- Observer looking at the paper

I and $\vec{B}$ are $\perp^r$ to each other

(Need to find $\vec{B}$ direction at points P, Q, R and S)



$\vec{B}$ $\perp^r$ to I and ~~upwards~~ towards the observer

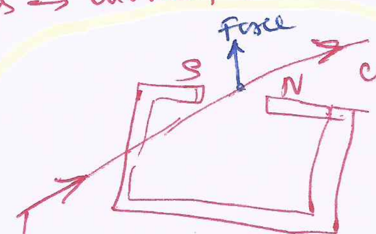
$\vec{B}$ $\perp^r$ to I and away from observer.

- For points P & Q, hold thumb $\perp^r$ to page and point fingers towards points P and Q, then palm is facing the observer. Therefore, $\vec{B}$ is on the plane of the page and towards the observer.
- Similarly for points R and S

Note that **Palm Rule No 1** is applicable for finding direction of $\vec{B}$ due to a current-carrying straight conductor

Note that there are other palm rules applicable for different cases. Examples are given below.

Ex: Force on a current-carrying conductor placed in a magnetic field. (3 parameters → current, $\vec{B}$ and Force (Motion))



Conductor is lifted upwards. Reversing the direction of current, conductor moves downwards.

Stretch Right-hand palm

Thumb → direction of Current I

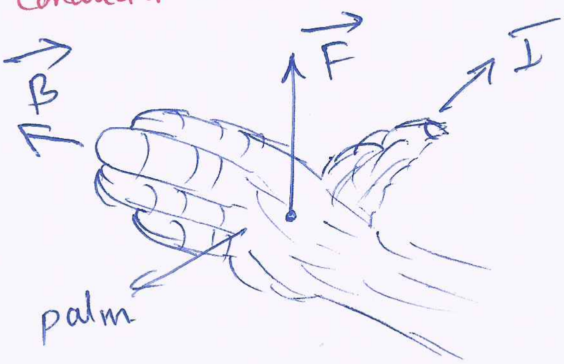
Stretched fingers → $\vec{B}$

$\perp^r$ to palm → Force $\vec{F}$ on the conductor will be $\perp^r$ to the palm in the direction of pushing by the palm.

Right hand palm Rule #2

⇓

This is same as "Fleming's Left-hand rule"



P.T.O

Fleming's Left hand Rule : → This is used to find the direction of motion (force) of ~~the~~ a current-carrying conductor in a magnetic field.

Here 3 parameters
- magnetic field $\vec{B}$
- force (motion) $\vec{F}$
- current I

Fleming's LH Rule : use left hand

Forefinger, Middle finger and the thumb are stretched mutually $\perp^r$ to one another such that

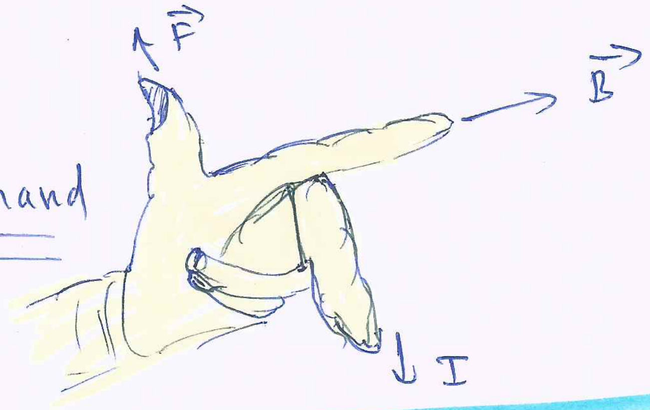
Fore-finger → mag. field $\vec{B}$

Middle finger → direction of current

then the thumb will point in the direction of force (motion) $\vec{F}$ on the conductor (current-carrying).

Left-hand

used for electric motors



Note : Fleming's Right-hand rule is used for AC/DC Generators. (I is induced current)

~~Fleming's RH Rule~~

Fleming's Right-hand rule → Generators (Mechanical energy → electrical energy)

Fleming's Left-hand rule → Electric Motors (Electrical energy → Mechanical energy)

Direction Rules (consolidation)

To find direction of $\vec{B}$ due to current-carrying straight conductor	To find the "motion of" "Force on" current-carrying conductor placed in a Magnetic field
① Right-hand Thumb rule ② Maxwell's RH Screw rule ③ Right-hand palm rule #1	① Fleming's Left-hand Rule ② Right hand palm rule #2. Electrical energy → Mechanical energy. (Motors)

To find direction induced current due to motion of Conductor in a magnetic field

[Mechanical energy → Electrical energy] (Generators AC or DC)

① Fleming Right-Hand Rule. (also known as Generator Rule)

→ Stretch right hand thumb and two nearby fingers ⊥r to one another

{ Thumb → Motion of conductor
Fore finger → Magnetic field }

hence → Middle finger indicates → Direction of induced emf or current

→ See AC Generator (page 15)

Elecktromagnetic Induction

(Note that there is no flow of a physically observable quantity)

Faraday, in 1831, discovered that whenever the number of magnetic lines of force (or magnetic Flux) passing through a circuit changes, an emf is induced in the circuit. ~~If the~~

→ If the circuit is closed, ~~a~~ a current flows through it (called as "induced current")

→ If the circuit is open (or infinite Resistance), emf will still be induced but there will be no current. This shows that the change in mag. flux induces emf, not the current.

The emf and the current (if circuit is closed) so produced are called ~~as~~ "induced emf" and "induced current" and will last only while the mag. flux is changing. The phenomenon is known as "electromagnetic induction".

Magnetic Flux through a circuit may be changed in a number of ways.

- by moving a magnet relative to the circuit
- by changing current in a neighbouring circuit
- by changing current in the same circuit
- by rotating a coil in a magnetic field

— 7a —

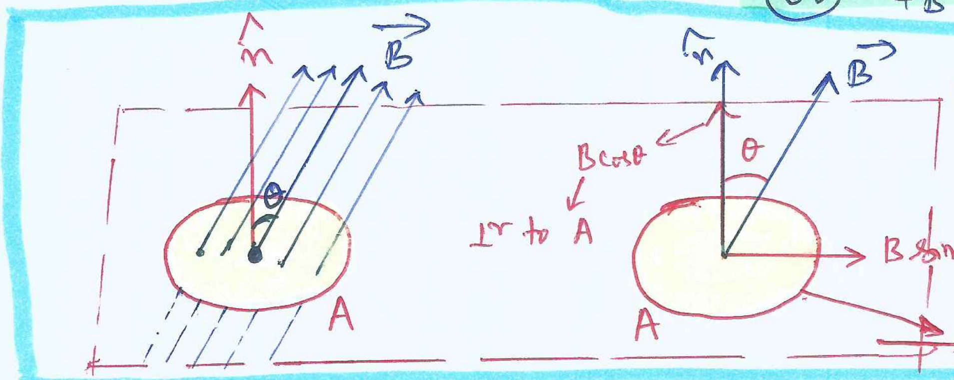
What is magnetic Flux (ϕ_B) $\longrightarrow$ ϕ_B is a Scalar quantity.

Defn: Magnetic flux (ϕ_B) through any surface is defined as the total number of magnetic ~~lines~~ field lines passing thro' that surface.

Consider a small surface of area A. Let $\hat{n}$ be the unit vector which is drawn normal to the plane of the surface. If θ is the angle betn $\hat{n}$ and the uniform mag. field $\vec{B}$, then the magnetic flux ϕ_B thro' the surface is given by $\phi_B = \vec{B} \cdot \vec{A} = B\,A\cos\theta$

or $\phi_B = (B\cos\theta)\,A$

a Note that there is no flow of physically ~~quantity~~ observable quantity.



Defn: → Magnetic flux ϕ_B through a given surface is defined as the product of the area of the surface and the component of the mag. field normal to the plane of the surface.

OR

Def2 → Magnetic flux ϕ_B thro' a given surface is defined as the product of the magnetic field and the area of the surface normal to the Plane of the surface.

∴ θ is the angle betn normal to the magnetic field and the surface
or θ is the angle betn the mag. field and a vector normal to the surface.

① when $\theta = 0°$, $\vec{B}$ is $\perp^r$ to the plane of the surface; $\phi_B = BA$ = maximum
⇒ max. no of mag. field lines pass through the given surface.

② when $\theta = 90°$, $\vec{B}$ is ∥ to the plane of the surface; $\phi_B = BA\cos 90° = 0$
⇒ mag. flux thro' the given surface is Zero when $\theta = 90°$.

problem: If $\theta = 25°$, how much smaller is the mag. flux thro' the area as compared ~~to~~ to when $\theta = 0°$.

Ans: $\phi_B = BA\cos\theta = BA\cos 25° \simeq BA \times 0.91 \approx 0.9\,BA$ [@ 25°]

$\phi_B = 1.0\,BA$ [@ 0°]

∴ when A is tilted by $\theta = 25°$, ϕ_B is smaller by 9 % than thro' the area normal to the field ($\theta = 0°$)

SI unit of Mag. Flux ϕ_B = Weber (Wb) ⇒ 1 Wb = 1 Tesla × 1 m²
1 Wb = 1 T m²

CGS System ϕ_B = ~~Max~~ maxwell (1 maxwell = 10^{-8} weber)

$\phi_B = BA\cos\theta$ is valid only if $\vec{B}$ is uniform thro' the surface. If $\vec{B}$ is variable within the given surface, then the surface is divided into very small area elements having constant $\vec{B}$. ∴ $\phi_B = \vec{B}_1 \Delta\vec{A}_1 + \vec{B}_2 \Delta\vec{A}_2 + \vec{B}_3 \Delta\vec{A}_3 + \cdots = \sum \vec{B}\cdot\Delta\vec{A}$, If $\Delta\vec{A} \to 0$, then $\boxed{\phi_B = \int_S \vec{B}\cdot d\vec{A}}$

Faraday's Laws of Electromagnetic Induction:

"The magnitude of the induced emf in a circuit is equal to time rate of change of magnetic flux through the circuit"

The above is normally called First law of Faraday's e-m induction. This is also known as "Neumann's law".

Mathematically, the induced emf is given by

$$\boxed{\mathcal{E} = -\frac{d\phi_B}{dt}} \longrightarrow (1)$$

If $\Delta\phi_B$ be the change in mag. flux in a time-interval Δt, then the emf induced in the circuit is given by $\mathcal{E} = -\frac{\Delta\phi_B}{\Delta t}$

In the limit $\Delta t \to 0$, we can write $\boxed{\mathcal{E} = -\frac{d\phi_B}{dt}} \longrightarrow (1)$

The negative sign in (1) indicates the direction of $\mathcal{E}$ and hence the direction of induced current in a closed loop

If $d\phi_B$ is in "weber" and dt in 'second', then the induced emf will be in 'volt'

In the case of a closely wound coil of N turns, change of flux associated with each turn is the same. Therefore, the total induced emf is given by

$$\boxed{\mathcal{E} = -N\frac{d\phi_B}{dt}} \longrightarrow (2)$$

~~$\mathcal{E}$ is directly~~

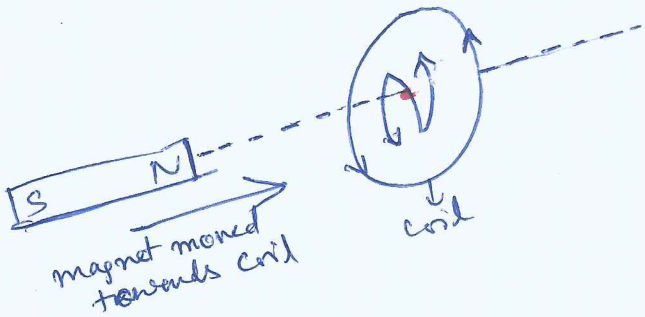
- The induced emf can be increased by
  - → increasing number of turns N of a closed coil
    - $\mathcal{E}$ is directly $\propto^l$ to N.
  - → when change in time Δt is smallest, $\mathcal{E}$ is inversely proportional to Δt
  - → when mag. flux is increased (we know that $\phi_B = \vec{B}\cdot\vec{A} = BA\cos\theta$)
    - So flux can be varied by changing any one or more of the terms B, A and θ.
- If the coil is an open circuit (infinite Resistance), emf will still be induced but there will be no current. This shows that change in flux induces emf, not the current.

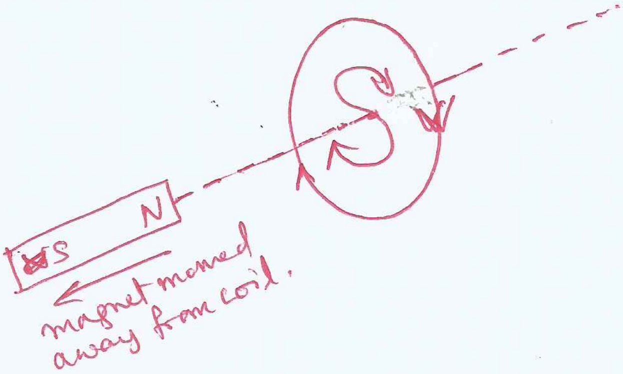
P.T.O.

Second law: The direction of induced emf, or the current (in a closed circuit), in any circuit is such as to oppose the cause that produces it. This is also known as Lenz's law

* Faraday was aware of the direction, however Lenz stated it properly and hence 2nd law is called Lenz's law.

Explanation of Lenz's law:





In the above magnet and coil experiment, the direction of induced current is in accordance with Lenz's law, that is, it opposes the motion of the magnet which produces it.

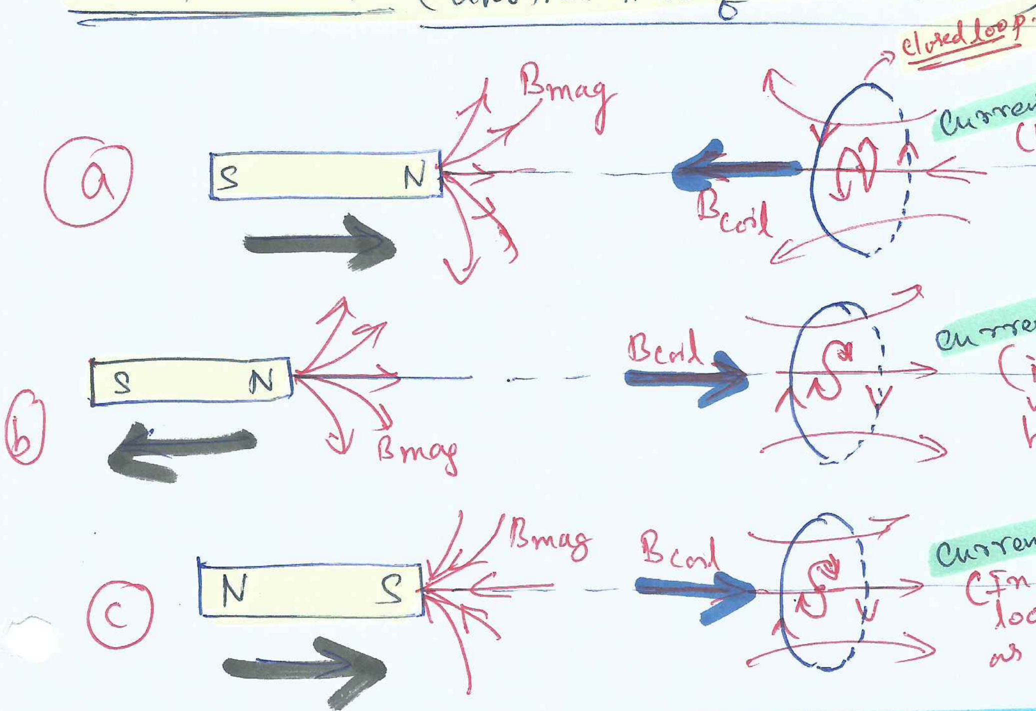
→ When N-pole of magnet is moved towards the coil, the induced current flows in a direction so that the near (left) face of coil acts as a magnetic north pole. Hence the repulsion betw like poles opposes the motion of the magnet towards the coil.

→ Similarly, when N pole of magnet is moved away from the coil, the direction of the induced ~~cu~~ current is such as to make the near face of the coil a south pole. The attraction of unlike poles opposes the motion of the magnet away from the coil.

- In either case, work has to be done in moving the magnet. It is this mechanical ~~energy~~ work which appears as electrical energy in the coil.
- A person has to do work in moving the magnet. Where does the energy spent by the person go? → This energy is dissipated by ~~jou~~ joule heating produced by the induced current.
- Direction of induced emf: Fleming's Right hand Rule

(See page 6)

Information: (another view of Lenz's law)



(a) Current → anticlockwise direction (when magnet is moved towards closed coil, mag. flux in the closed loop increases the current in the loop is anticlockwise

(b) current → clockwise direction (in this case, flux ~~decreases~~ linked with the closed loop decreases, hence current in the loop is clockwise)

(c) Current → clockwise direction (In this case, flux linked with closed loop increases in the opposite direction as compared to case (a), and hence current is clockwise (same as case (b))

(a) → When magnet is ~~moved~~ thrust into the coil, the strength of the magnetic field increases in the coil. The current induced in the coil creates another field, in the opposite direction of the bar magnet's field to oppose the increase. This is one aspect of Lenz's law – induction opposes any change in flux.

(b) and (c) → are two other situations.

Since the induced emf is in opposing direction, law of conservation of energy is maintained. Lenz's law is a manifestation of the conservation of energy. The induced emf produces a current that opposes the change in flux, because a change in flux means a change in energy. Energy can enter or leave, but not instantaneously. Lenz's law is a consequence. As the change begins, the law says induction opposes and thus, slows the change.

In fact, if the induced emf ~~[illegible]~~ were in the same direction as the change in flux, there would be a positive feedback that would give us free energy from no apparent source – conservation of energy would be violated.

IMP

how did we determine direction of $\vec{B}$? See page (11)

From page (10), how do we determine the direction of induced current in the ~~coil~~ circular coil.

Take case (a)

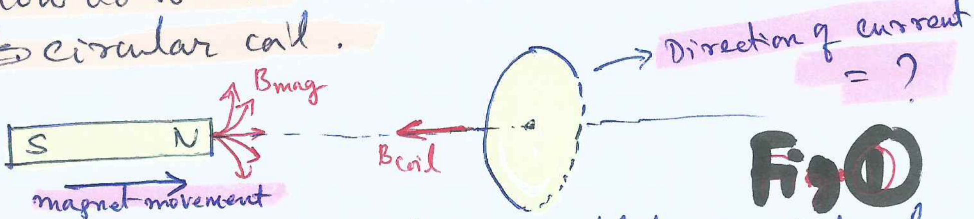
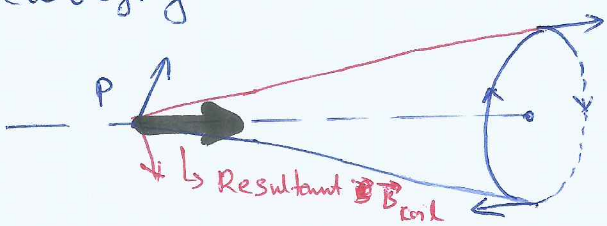


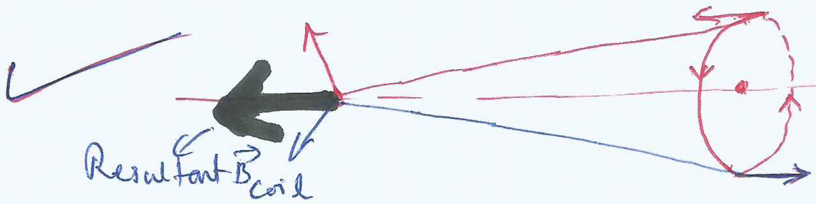
Fig (1)

- From above figure, as per Lenz's law, there should be an induced emf (current if closed loop) in the coil that opposes the motion of magnet which produces it. This means, in above figure, when magnet is moved towards right through the coil, there should be an opposing magnetic field (B_{coil}) that ~~would~~ has been created by the current carrying ~~circular~~ circular coil. This means B_{coil} should be directed towards left (as shown in figure)
- To get $\vec{B}_{coil}$ towards left, the current in the coil should be in some definite direction. We need to find out whether ~~current~~ current in coil is clockwise or anticlockwise. See below point.
- We know that magnetic field at the axis (or center) of a current-carrying circular coil.



if current is clockwise

~~Fig~~ Fig (2)

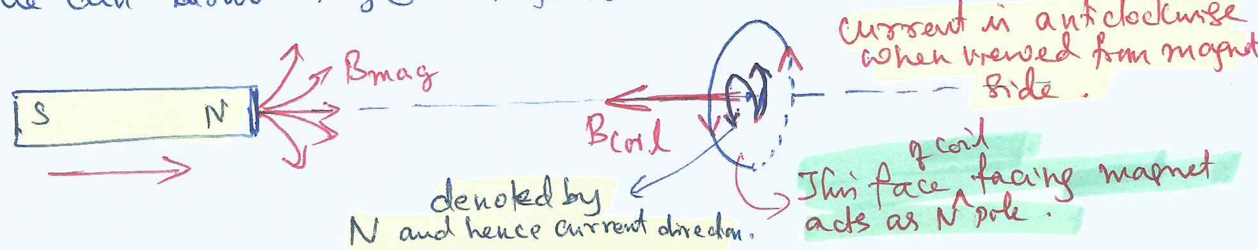


if current is Anticlockwise

Fig (3)

- Since we require Fig (3) as per Lenz's law, the current in the loop should be anticlockwise.

  This proves the direction of induced current as given in page (10) case (a). Similarly for other cases in page (10).
- So left face of coil acts as magnetic north pole. Hence, repulsion that opposes the motion of magnet towards the coil.
- So we can ~~draw~~ draw Fig (1) as follows



- Consider an electrically conducting ring or coil loop. The loop could be cut at one place to connect a Galvanometer in series to detect the current.
- In Fig. 30-4, with the magnet initially at a distant from loop, no magnetic flux passes through the loop and hence no induced current in the loop and Galvanometer shows no deflection. If the bar magnet is stationary, there is no induced current in the loop.
- As the north pole of the magnet enters the loop (**along the axis of the loop**) with its magnetic field directed **downwards and perpendicular to loop**, **the flux through the loop increases**. **(Let us denote this external magnetic field due to magnet as $\vec{B}$)**
- As per Faraday's law, since there is a **change** (*in this case → increase*) in **flux** wrt time through the loop, a current is induced in the loop (and is detected by Galvanometer).
- As we know, this induced current (*produced due to magnet's movement*) in the loop sets-up its **own magnetic field** (say $\vec{B}_{ind}$) whose direction is to oppose this increase in flux due to $\vec{B}$ as per Lenz's law. So, $\vec{B}_{ind}$ should be **upwards and perpendicular to loop**.
- To produce this upward $\vec{B}_{ind}$, the induced current "I" in the loop must be in **anti-clockwise direction** (*as viewed from above the loop*) as per Right Hand Thumb rule

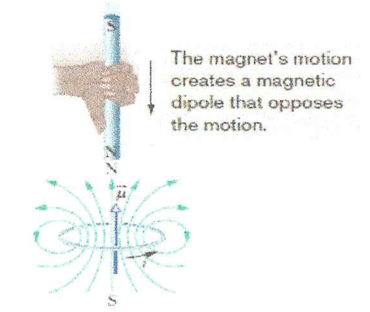
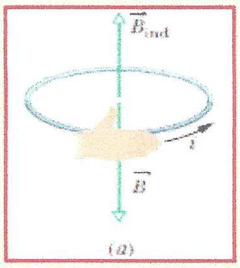
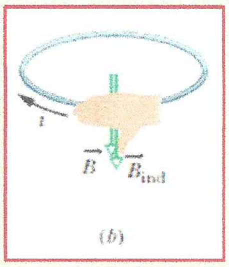
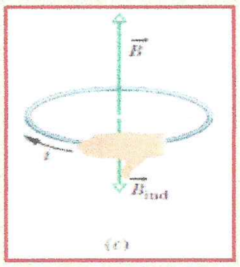
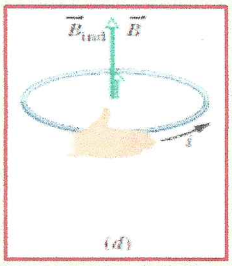


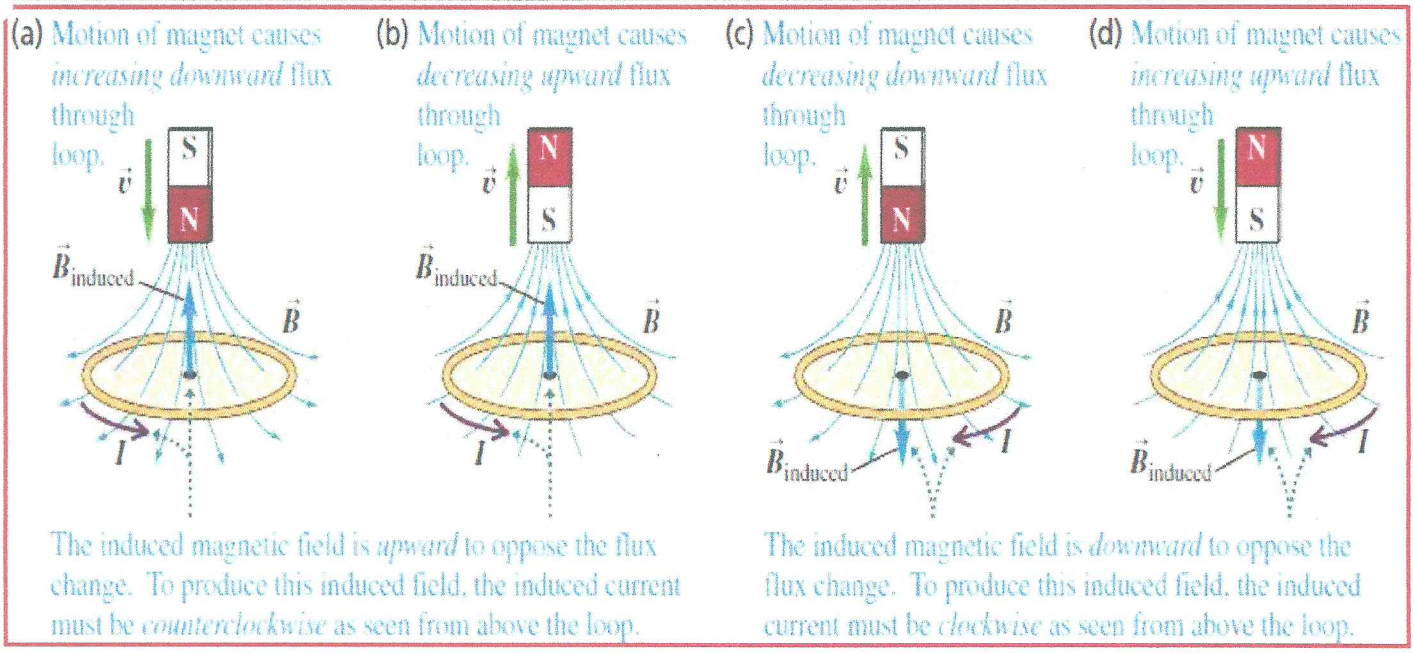
Figure 30-4 Lenz's law at work. As the magnet is moved toward the loop, a current is induced in the loop. The current produces its own magnetic field, with magnetic dipole moment $\vec{\mu}$ oriented so as to oppose the motion of the magnet. Thus, the induced current must be counterclockwise as shown.

Important tips :

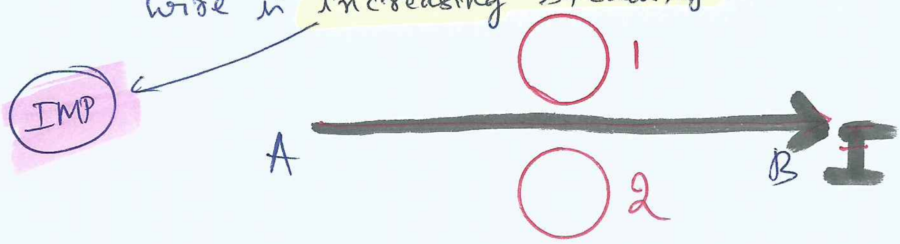
- The flux of $\vec{B}_{ind}$ always opposes the change in the flux of $\vec{B}$.
- **But $\vec{B}_{ind}$ is not always opposite to $\vec{B}$**
- For example, if we pull the magnet away from the loop in Fig. 30-4, the magnet's flux ϕB is still downward through the loop, but it is now decreasing. The flux of $\vec{B}_{ind}$ must now be downward inside the loop, to oppose that decrease (as in Fig b below). **Thus, $\vec{B}_{ind}$ and $\vec{B}$ are now in the same direction.**

	Increasing the external field $\vec{B}$ due to magnet induces a current with a field $\vec{B}_{ind}$ that *opposes the change* (N-pole of magnet entering the loop)	Decreasing the external field $\vec{B}$ due to magnet induces a current with a field $\vec{B}_{ind}$ that *opposes the change* (N-pole of magnet retreating the loop)	Increasing the external field $\vec{B}$ due to magnet induces a current with a field $\vec{B}_{ind}$ that *opposes the change*. (S-pole of magnet entering the loop)	Decreasing the external field $\vec{B}$ due to magnet induces a current with a field $\vec{B}_{ind}$ that *opposes the change*. (S-pole of magnet retreating the loop)
The induced current creates this field, trying to offset the change. The fingers are in the current's direction; the thumb is in induced field direction. (*as viewed from above the loop*)	 **Current I is anticlockwise**	 **Current I is clockwise**	 **Current I is clockwise**	 **Current I is anticlockwise**

In the above fig, the direction of the current I induced in a loop is such that the current's mag field $\vec{B}_{ind}$ opposes the change in the mag field $\vec{B}$ inducing I. The field $\vec{B}_{ind}$ is always directed opposite an increasing field $\vec{B}$ (a,c) and in the same direction as a decreasing field $\vec{B}$ (b,d). The Right Hand Thumb Rule gives the direction of the induced current based on the direction of the induced field.



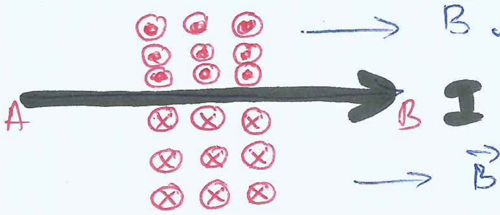
problem: predict the directions of induced currents in metal rings ① and ② lying in the same plane where current I in the wire is increasing steadily.



Assume Conductor AB, coils ① and ② are on the plane of paper

- Assume Conductor AB and coils ①&② are on the plane of paper.
- There are 2 parts to this question
  - (a) we need to find direction of $\vec{B}$ above ~~and~~ and below the current-carrying conductor AB.
  - (b) Secondly, ~~do~~ to find direction of induced current in coils ① and ②.

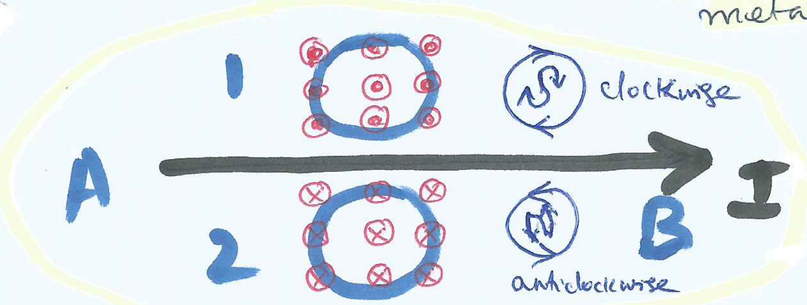
(a) As per Right hand Thumb rule (or) Right hand palm rule #1,



→ $\vec{B}$ is $\perp^r$ to plane of paper and pointing upwards

→ $\vec{B}$ is $\perp^r$ to plane of paper & pointing downwards.

(b) Second part is when metal rings ① and ② are placed in a magnetic field generated by current-carrying conductor AB, the induced current is developed in metal rings ~~A and~~ ① and ②.



~~g~~ We need to find the direction of induced current in metal rings ① and ②. The direction of current is such that to oppose increase of mag. field due to conductor AB.

Ring ①: → $\vec{B}$ due to AB is $\perp^r$ to plane of paper and upwards ($\vec{B}_{AB}$). This $\vec{B}_{AB}$ induces current in ring①. The induced current in ring① creates another magnetic field in the opposite direction of $\vec{B}_{AB}$.
So, when $\vec{B}_{AB}$ is $\perp^r$ to plane of paper & upwards, $\vec{B}_{Ring1}$ is $\perp^r$ to plane of paper and downwards (to ~~op~~ oppose increase in $\vec{B}_{AB}$).
So, current in ring ① should be clockwise so that $\vec{B}_{ring1}$ is downwards. Therefore, upper face of ring①, acts like South pole and hence current in ring① is CLOCKWISE direction.

Ring ②: → Similarly, induced current in Ring ② is Anti-clockwise.

 (Nootan Book page # 514)

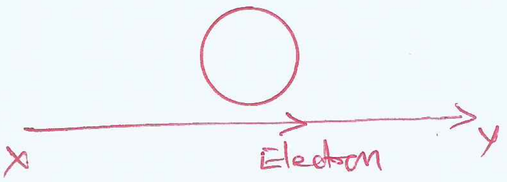
Problem In previous problem in page (12)

(1) If current is from B to A and steadily increasing
Ans: Induced current in Ring (1) is in anticlockwise direction
—— do —— in Ring (2) is in clockwise direction.

(2) If current is from B to A and steadily decreasing
Ans: Induced current in Ring (1) is in clockwise direction.
—— do —— (2) is in Anticlockwise direction.

(3) If current is from A to B and steadily decreasing
Ans: Induced current in Ring (1) is in anticlockwise direction
—— do —— (2) is in clockwise direction.

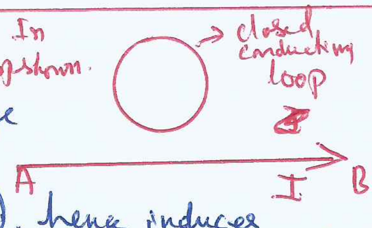
(4) An electron moves along the line XY lying in the same plane as a circular conducting loop. Which statement is true for the direction of ~~induced~~ current induced, if any, in the loop?



(a) No current will be induced
(b) The current will be clockwise
(c) The current will be anticlockwise
(d) The current will change direction as the electron moves.

(5) When the current through a solenoid increases at a constant rate, the induced current:
(a) is a constant and is in the direction of the inducing current.
(b) is a constant and is opposite to the direction of the inducing current.
(c) increases with time and is in the direction of the inducing current.
(d) increases with time and is opposite to the direction of the inducing current.

Problem: (1) Current I in a wire AB is increasing at a steady rate. In which direction does the induced current flow in the closed loop shown.

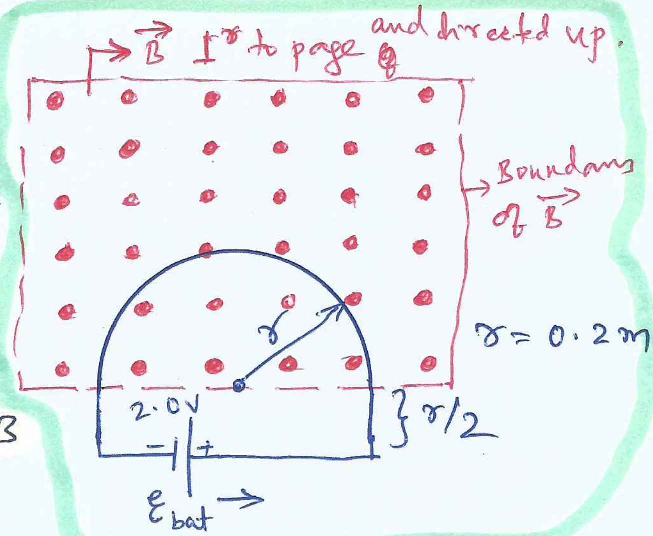


Ans: Clockwise; B_{AB} due to I passing thro' the loop is ⊥r to page and pointing upwards (RHTR or palm rule #1). This B_{AB} is varying (non-uniform due to steadily increasing current in AB), hence induces current in the loop (Faraday law). This $I_{induced}$ produces 2nd mag. field which opposes B_{AB} → therefore $B_{induced}$ is ⊥r to page and pointing downwards. As per RHTR, in order to generate this direction of $B_{induced}$, current in the loop must be in clockwise direction.

(2) (3) If the st. wire AB carries steady current of magnitude I Amperes, then?
→ Ans: Induced current is zero (there is no induced current). How? → Current I (steady) in AB will definitely produce mag. field B_{AB} (which is ⊥r to page and upwards) but is uniform. $\Phi = BA$ → B is const., A is constant. Induced emf $= d\phi/dt = 0$ → hence there is no induced emf and hence no induced current. (ϕ_B is not changing with time)

problem. — 13 A —

Fig. shows conducting loop consisting of half-circle of radius = 0.2 m and three straight sections. The half-circle lies in a uniform mag. field $\vec{B}$ that is ⊥ to page and ~~directed up~~ pointing upwards. Magnitude of $\vec{B}$ is given ~~by~~ as $\vec{B} = 4t^2+2t+3$ ($\vec{B}$ in tesla and t in secs). An ideal battery with emf $\mathcal{E}_{bat} = 2.0\,V$ is connected to the loop. The resistance of loop = 2.0 Ω.



(a) What are the magnitudes and direction of the emf $\mathcal{E}_{ind}$ around the loop by field at $t = 10$ s ?

(b) What is the current in the loop at $t = 10$ s ?

Ans: From Faraday's law $\mathcal{E}_{ind} = \dfrac{d\phi_B}{dt} = \dfrac{d}{dt}(BA)$

From given figure, A is constant and B changes with time. $\Rightarrow \mathcal{E}_{ind} = A\dfrac{d\vec{B}}{dt} = A\dfrac{d}{dt}(4t^2+2t+3)$

Since given $\vec{B} = 4t^2+2t+3$

~~$\mathcal{E}_{ind}$~~ Since $A = \frac{1}{2}\pi r^2$ (half-circle)

$$\mathcal{E}_{ind} = \frac{\pi r^2}{2}(8t+2) \rightarrow (1)$$

(a) At $t = 10$ s, $\mathcal{E}_{ind} = \dfrac{\pi r^2}{2}(\cancel{82})^{41}$

$= \pi(0.2)^2 \times 41$

$\simeq \boxed{5.2\,V}$ Ans

To find direction of $\mathcal{E}_{ind}$, note that external flux through the loop is out of page and increasing. Because the induced field B_{ind} (due to induced current) must oppose this increase, B_{ind} must be into the page. Using ~~RHR~~ RHTR, induced current must be clockwise around the loop to enable B_{ind} to be into the page opposing external $\vec{B}$.

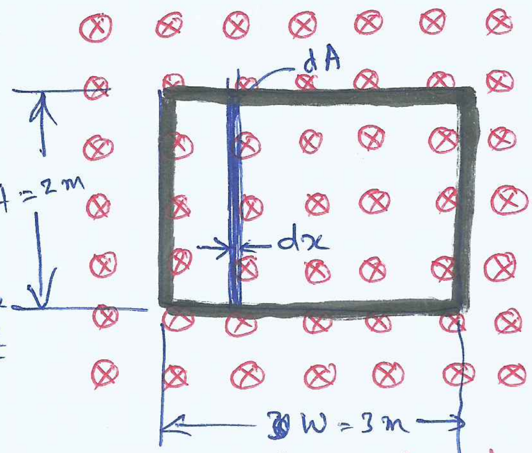
(b) To find current: The point here is that 2 emfs tend to move charges around the loop; The induced emf $\mathcal{E}_{ind}$ tends to drive a current clockwise around the loop, the battery emf $\mathcal{E}_{bat}$ tends to drive current anticlockwise. Since $\mathcal{E}_{ind} = 5.2$ and $\mathcal{E}_{bat} = 2.0$, $\mathcal{E}_{ind} > \mathcal{E}_{bat} \Rightarrow$ the net ~~current~~ ~~is clockwise~~. emf is clockwise and hence current. (Given $R = 2\,\Omega$)

$$I = \frac{\mathcal{E}_{net}}{R} = \frac{\mathcal{E}_{ind}-\mathcal{E}_{bat}}{2} = \frac{5.2-2.0}{2} = \frac{3.2}{2} = 1.6\,A \rightarrow (2)$$

END

problem : — 13 B —

Fig. shows a rectangular loop of wire immersed in a non-uniform and varying mag. field $\vec{B}$ that is $\perp^r$ to and directed into the page. The field's magnitude is $B = 4t^2x^2$ teslas (note function $\vec{B}$ depends on both time and position). Loop width $W = 3m$, height $H = 2m$. What are the magnitude and direction of the induced emf $\mathcal{E}$ around the loop at $t = 0.1S$?



Ans. Since B is changing with time, flux ϕ_B through the loop also changes. So changing flux induces emf as per Faraday's law. $\mathcal{E} = \frac{d\phi_B}{dt}$.

We need expression for ϕ_B.

→ If the field varies with position (since $B = 4t^2x^2$), we must integrate to get the flux through the loop.

→ Assume a ~~thin~~ strip so thin that we can approximate the field as being uniform within it.

$\therefore$ Flux ϕ_B through area dA : $dA = H\,dx$ (height × width)

$$\phi_B = \int \vec{B}\cdot\vec{dA} = \int B\,dA = \int BH\,dx = \int 4t^2x^2H\,dx$$

Treating t as a constant for this integration and inserting the limits $x=0$ and $x = 3m$, we get

$$\phi_B = 4t^2H\int_0^3 x^2dx = 4t^2 \underset{2m}{H}\left[\frac{x^3}{3}\right]_0^3 \; (H = 2m) = \boxed{72t^2} \rightarrow (1)$$

As per Faraday's law $\mathcal{E} = \frac{d\phi_B}{dt} = \frac{d}{dt}(72t^2)$

$\mathcal{E} = 144t$

At $t = 0.1S$, $\boxed{\mathcal{E} \simeq 14\,V} \longrightarrow (2)$

Direction of $\mathcal{E}$ (or I).

- $\vec{B}$ through the loop is $\perp^r$ to page and directed downwards.
- Since $\vec{B} = 4t^2x^2$, its magnitude is increasing with time.
- By Lenz's law, the induced ~~emf~~ field B_{ind} (due to induced emf and current) must oppose this increase, so $\vec{B}_{ind}$ should be $\perp^r$ to page and directed upwards.
- As per RHTR, to get $\vec{B}$ upwards, current in the loop must be anticlockwise.

END.

problem:

Following table shows a map of a non-uniform mag. field measured near a sheet of mag. material. If the central marked region represents a "loop of wire", what is the mag. flux thro' the loop.

→ Magnetic field $\vec{B}$

(All numbers represent $|\vec{B}|$ in mT (milli Tesla) out of the page.

→ Each grid line = 1 cm spacing

$\therefore$ Area of each small grid $= 10^{-4} m^2$

1 cm | 1 cm

6	6	6	6	6	5	5	6	6	6
6	6	6	6	6	5	5	6	6	6
5	5	6	5	6	6	5	5	5	5
5	6	5	5	5	4	4	5	5	6
5	5	4	4	5	3	5	5	5	5
5	5	4	4	3	4	4	3	5	5
4	4	4	4	3	3	3	3	3	4
3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	3	3

Conducting loop

What is the Mag flux ϕ_B thro' this loop?

Ans: I Method:

- General formula for uniform $\vec{B}$ = $\phi_B = B \cdot A = BA\cos\theta$ | $\theta = 0^0$, $\cos 0^0 = 1$

$$\boxed{\phi_B = BA}$$

- When $\vec{B}$ is non-uniform,

$$\phi_B = B_1 A_1 + B_2 A_2 + \dots\dots$$

$A = 10^{-4} m^2$

For $\vec{B} = 1\,mT$

$\vec{B} = 10^{-3}\,T$

$BA = 10^{-4} \times 10^{-3}\,Wb$

$= 10^{-7}\,Wb$

$$\therefore \phi_B = 10^{-7}[6+5+6+6+5+ \\ 5+5+5+4+4+ \\ 4+4+5+3+5+ \\ 4+4+3+4+4+ \\ 4+4+3+3+3 \\ 3+3+3+3+3]$$

$$\therefore \phi_B = 10^{-7}[28+23+21+19+17+15] = 123 \times 10^{-7}\,Wb$$

$$\phi_B = 12.3\,\mu Wb \quad \text{or} \quad 0.0123\,mWb$$

Ans: II Method:

$\phi_B = BA$

$= 4.1 \times 10^{-3}\,T \times 3 \times 10^{-3}\,m^2$

$= 12.3 \times 10^{-6}\,Wb$

$= 12.3\,\mu Wb$

or $= 0.0123\,mWb$.

Area of loop

$= 5\,cm \times 6\,cm = 30\,cm^2$

$= 30 \times 10^{-4}\,m^2$

$A = 3 \times 10^{-3}\,m^2$

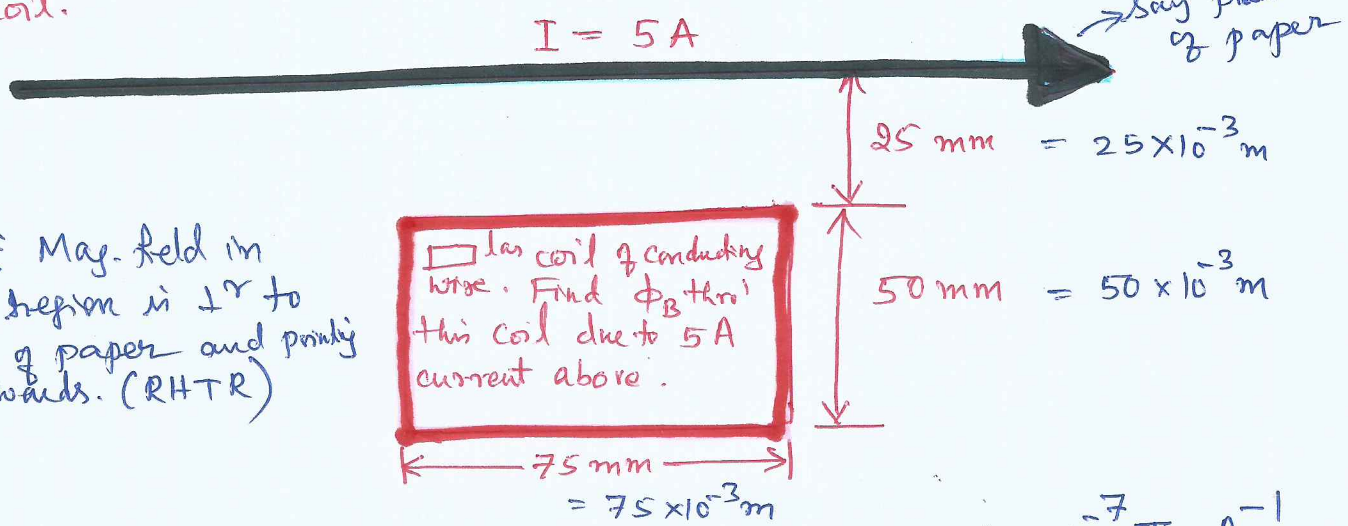
Average $\vec{B}$ in the loop

$\frac{123}{30} = 4.1\,mT$

$|\vec{B}| = 4.1\,mT$

problem: $\boxed{-13\,d-}$

Figure below shows a rectangular loop of wire placed near a current-carrying wire. Using dimensions shown in figure, find the magnetic flux thro' the coil.



Info: Mag. field in this region is $\perp^r$ to plane of paper and pointing downwards. (RHTR)

Ans: Formula: Ampere law $\boxed{|\vec{B}| = \frac{\mu_0}{2\pi}\frac{I}{r}}$

$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{TmA^{-1}}$

$\therefore \frac{\mu_0}{4\pi} = 10^{-7}\ \mathrm{TmA^{-1}}$

$\therefore |\vec{B}| = \frac{\mu_0}{4\pi}\cdot\frac{2I}{r} = 10^{-7} \times \frac{10}{r}$ (Since given $I = 5$ A)

$$\boxed{|\vec{B}| = \frac{1}{r}\,\mu T} \rightarrow (1) \quad \therefore \boxed{|\vec{B}| \propto \frac{1}{r}}$$

(So, magnitude of magnetic field decreases as we move away from current-carrying straight conductor)

example:

@ 25 mm below wire

$|\vec{B}_{25}| = \frac{1}{25\times10^{-3}}\,\mu T = \frac{1000}{25}\,\mu T = 40\,\mu T$

@ 75 mm below wire

$|\vec{B}_{75}| = \frac{1}{75\times10^{-3}}\,\mu T = \frac{1000}{25}\,\mu T = 13.3\,\mu T$

→ calculate average $|\vec{B}|$ using (1)

$$|\vec{B}| = \frac{10^{-6}}{50\times10^{-3}}\int_{0.025}^{0.075}\frac{1}{r}\,dr = \frac{10^{-3}}{50}\Big[\ln(r)\Big]_{0.025}^{0.075}$$

$$\boxed{|\vec{B}| = \frac{10^{-3}}{50}\left[-2.6 + 3.7\right] = \frac{10^{-3}}{50}\times 1.1}$$

$\therefore$ Magnetic flux $\phi_B = BA\cos\theta$ $(\theta = 0)$, $\cos\theta = 1$

$\phi_B = BA$

Area of loop

$A = 75\,\mathrm{mm} \times 50\,\mathrm{mm}$

$A = 75\times50\times10^{-6}\,\mathrm{m^2}$

$A = 75\times5\times10^{-5}\,\mathrm{m^2}$

$A = 375\times10^{-5}\,\mathrm{m^2}$

$$\phi_B = \left(\frac{10^{-3}\times1.1}{50}\,T\right)\left(375\times10^{-5}\,\mathrm{m^2}\right)$$

$$= \frac{1.1\times375}{50}\times10^{-8}\ \mathrm{Wb}$$

$$\boxed{\phi_B \simeq 8\times10^{-8}\ \mathrm{Wb}} \rightarrow \text{Ans.}$$

Since flux is not changing with time (Since I = 5A is steady constant current), there is no induced current in the □lar coil.

~~Extra: Due to above flux, emf is induced in the coil. Since the coil is a closed circuit, there is an induced current. Direction of induced current in the coil is anti-clockwise. Since, B_{wire} is downwards, B_{coil} should be upwards. To get upward B_{coil}, the current in the coil should be anticlockwise.~~ (See page 13)

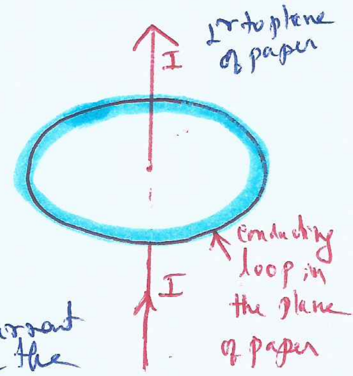
(1) A conducting loop is held stationary normal to the field betⁿ the pole-pieces of a fixed permanent magnet. Can we produce current in the loop by choosing a very strong magnet.

→ NO, current is induced in the loop ONLY when there is a change in mag. flux linked with the loop

(2) A closed conducting loop moves normal to the electric field betⁿ the plates of a charged capacitor. Is any current induced in the loop when (i) it is wholly inside the capacitor, (ii) partially outside the plates of the capacitor.

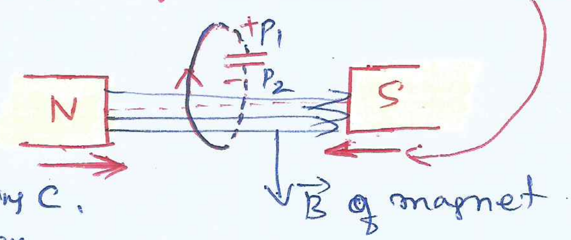
→ No current is induced in either case. Current is induced by a change in magnetic flux, not by a change in electric flux.

(3) The current I in a wire passing normally thro' the centre of a conducting loop is increasing at a constant rate. Will current be induced in the loop



→ NO, since mag. flux lines due to I lie in the plane of the loop (since I is moving ⊥r to plane of loop as shown in figure). Hence "$\vec{B}$ due to I" and "loop" are parallel.
$\phi_B = BA\cos\theta \rightarrow \theta = 90^\circ$, $\cos\theta = 0$ $\therefore \phi_B = 0 \Rightarrow$ no emf or current is induced in the loop.

(4) Mark the polarity of the capacitor when N and S pole of a magnet go closer to the coil having capacitor C? P_1 is +ve? or P_2 is +ve?



→ • Direction of $\vec{B}$ magnet is from N → S thro' the loop having C.
• $\vec{B}_{coil}$ should be from S → N → for this to happen, induced current is in anticlockwise direction (as viewed from N-pole side)
• As shown in figure, P_1 becomes +ve and P_2 will be negative.

(5) As the speed of bicycle is increased, the illumination of its lamp increases, why?

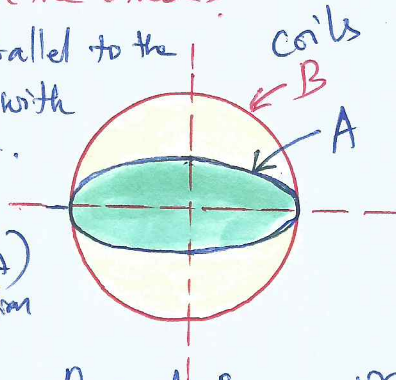
→ The bicycle lamp is illuminated (powered) by dynamo. On increasing the speed, $\frac{d\phi_B}{dt}$ increases (rate of change of mag. flux in the dynamo increases) and $\mathcal{E} = \frac{d\phi_B}{dt} \Rightarrow$ emf increases and hence lamp glows brighter.

(6) Two circular conductors A and B are ⊥r to each other (as shown). If current in one of them is changed, will current be induced in the other?

→ NO, since $\vec{B}$ due to current in a coil (A or B) will be parallel to the plane of the other coil (B or A). Hence the mag. flux linked with the other coil will be zero and no current is induced in it.

~~ex: If current in A is changed,~~

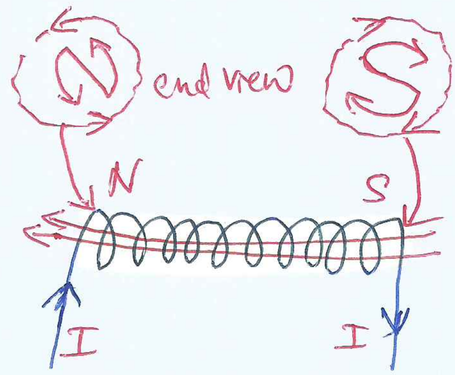
ex: Due to current in A, there develops a mag. field (due to I_A) if I_A changes, there is a change in mag. field whose direction is parallel to coil B. So, $\theta = 90^\circ$ $\therefore \phi_B = 0 \Rightarrow$ there is no induced current in coil B.

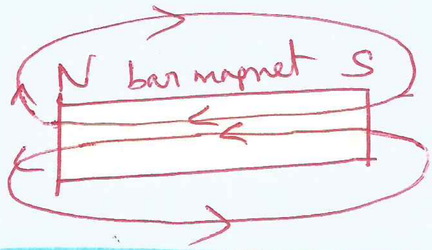


A and B are ⊥r to each other

— 13 f —

Solenoid: The mag field pattern for the solenoid looks very similar to that of a bar magnet (see fig), (Note: The idea that mag. field lines emerge from N-pole ~~to~~ and go into S-pole is simply a convention).

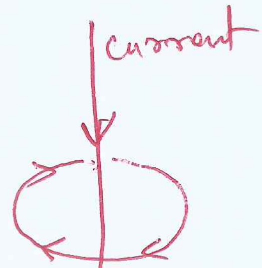




→ **Right-hand grip rule**:

The R-H grip rule gives the direction of mag. field lines in an electromagnet and a solenoid. Grip the solenoid so that right hand fingers go around it following the direction of the current. The thumb now points in the direction of the current inside the coil. i.e. it points towards the N-pole.

Note: IMP → The circular field around a straight wire carrying a current does not have magnetic poles. [use Right hand rule for the direction of mag. field → Grip the wire with your right hand pointing your thumb in the direction of conventional current, then the fingers curl around in the direction of the magnetic field.



* Right-hand Grip rule → applies to a solenoid
Right-hand rule → applies to a current in a straight wire.

① We know that $F = mg$. We define Gravitational field strength 'g' at a point as the force per unit mass $\boxed{g = \frac{F}{m}} \rightarrow$ ①

② Electric field strength E is defined as the force per unit positive charge $\boxed{E = \frac{F}{q}} \rightarrow$ ②

③ In a similar way, mag. flux density (or mag. field $\vec{B}$) is defined in terms of the mag. force experienced by a current-carrying conductor placed at right angles to a mag. field, the flux density is defined as $\boxed{B = \frac{F}{IL}} \rightarrow$ ③, where

- F is the force experienced by a current-carrying conductor
- I is the current in the conductor
- L is the length of the conductor in the uniform mag. field of flux density $\vec{B}$

→ The direction of force is given by Fleming's LHR.

Note: $\boxed{F = BIL}$ can be used only when field is $\perp^r$ to current.

Note: Mag. flux density ($\vec{B}$) can be measured using a Hall probe.

$\phi_B = B \cdot A$
$B = \phi_B / A$
ϕ_B = Mag. flux
∴ Mag. flux / Area is "magnetic flux density" $\vec{B}$. Therefore mag. flux density and mag. field are same $\vec{B}$.

◉ Force betw two 1kg masses 1m apart

$F = G\frac{m_1 m_2}{d^2}$; $G = 6.7 \times 10^{-11}\ N\,Kg^{-2}m^2$

Given $m_1 = m_2 = 1Kg$ and $d = 1m$

∴ $\boxed{F = 6.7 \times 10^{-11}\ N} \longrightarrow$ ④ Gravitational Force

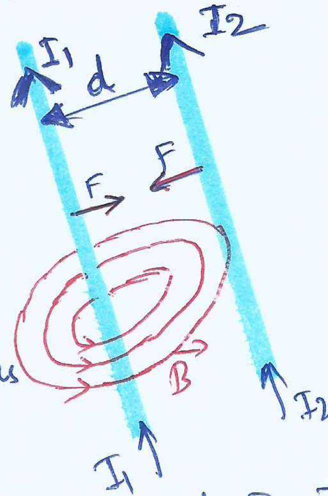
◉ Force betw two charges of 1C placed 1m apart } Given $q_1 = q_2 = 1C$, $d = 1m$

$F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{d^2}$; $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9\ C^{-2}Nm^2$

∴ $\boxed{F = 9 \times 10^9\ N} \longrightarrow$ ⑤ Electrical Force

◉ Force per meter on 2 wires carrying a current of 1 A placed 1m apart.

→ We know that a long straight wire carrying current I_1 produces a mag. field $\vec{B}$ (which forms concentric circles around the wire) whose magnitude at a distance d from wire is given by $B_1 = \frac{\mu_0 I_1}{2\pi d}$ with the direction given by right hand rule.



→ If a second parallel wire carrying a current I_2 is placed at a distance d from the first, it will feel a force due to B_1.

→ The force felt by a length L_2 of this second wire is

$F_2 = I_2 (L_2 \times B_1)$ $\boxed{\text{Since } B_1 = \frac{\mu_0 I_1}{2\pi d}}$

$|F_2| = \frac{\mu_0 I_1 I_2 L_2}{2\pi d}$ [direction → I_2 conductor is attracted towards I_1 conductor]

∴ Force per unit length on I_2 conductor is given by

$\frac{F_2}{L_2} = \mu_0 \frac{I_1 I_2}{2\pi d}$ Given $I_1 = I_2 = 1A$; $d = 1m$, $\mu_0 = 4\pi \times 10^{-7}\ T\,m\,A^{-1}$

∴ $\frac{F}{l} = \frac{\cancel{4\pi} \times 10^{-7}}{\cancel{2\pi}}\,2 = 2 \times 10^{-7}\ N$ ∴ $\boxed{\frac{\text{Force}}{\text{meter}} = 2 \times 10^{-7}N} \rightarrow$ ⑥

↓④, ⑤, ⑥ suggests → Electric force is strongest and gravity is the weakest. 10^{39} times

- Consider an electron moving around a proton in Hydrogen atom, the electrical force is significant the gravitational force. So for electron or small charged object, electrical force is gravitation forces.

- However, over larger distances and with objects of large mass, the gravitation becomes most significant. (For example, motions of planets in solar system are affected by the gravitational field but the electromagnetic forces are comparatively insignificant.)

IMP

— 13 h —

Info and problem.

We know that →

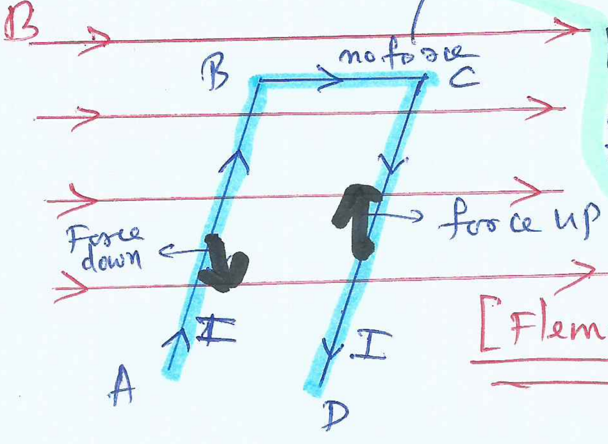
$\Phi_B = BA\cos\theta$

$\theta = 90^\circ$, $\cos 90^\circ = 0$

$\Phi_B = 0$

[conductor BC]

BC experiences no force when I is ∥ to field.



[Fleming's LHR]

Conductors AB and CD

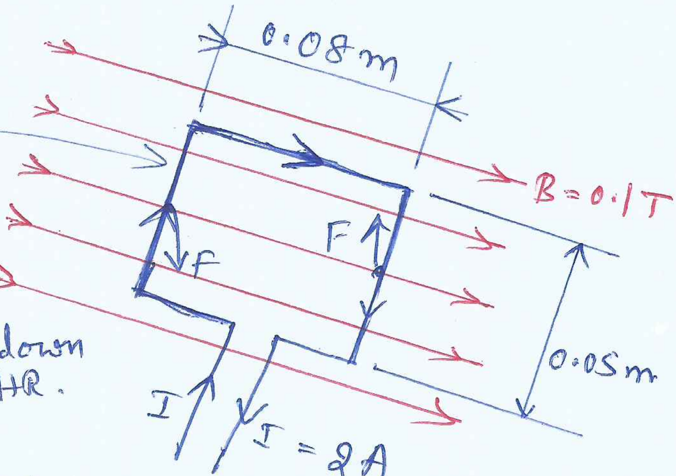
$\theta = 0^\circ$, $\cos\theta = 1$, $\Phi_B = BA$

As per Fleming LHR, force is as shown in figure.

problem :

An electric motor has a rectangular loop of wire with the dimensions shown in figure. The loop is in a mag-field of flux density 0.1 T. The current in the loop is 2A. Calculate the torque that acts on the loop in the position shown.

Given $B = 0.1\,T$, $I = 2\,A$, $L = 0.05\,m$



① $F = BIL$, calculate the force on one side of the loop

$F = BIL = 0.1 \times 2 \times 0.05$

$= 0.2 \times 0.05$

$= 0.010$

$\boxed{F = 0.01\,N}$ direction down as per FLHR.

② Similarly for other side, $F = 0.01\,N$ with direction up.

③ ∴ The two forces on the opposite sides of the loop are equal and anti-parallel. In other words, they form a "couple"

④ ∴ The torque (moment) of a couple is equal to magnitude of one of the forces times the ⊥r distance betn them.

The two forces are separated by 0.08 m (as in figure)

∴ torque = force × separation = 0.01 N × 0.08 m

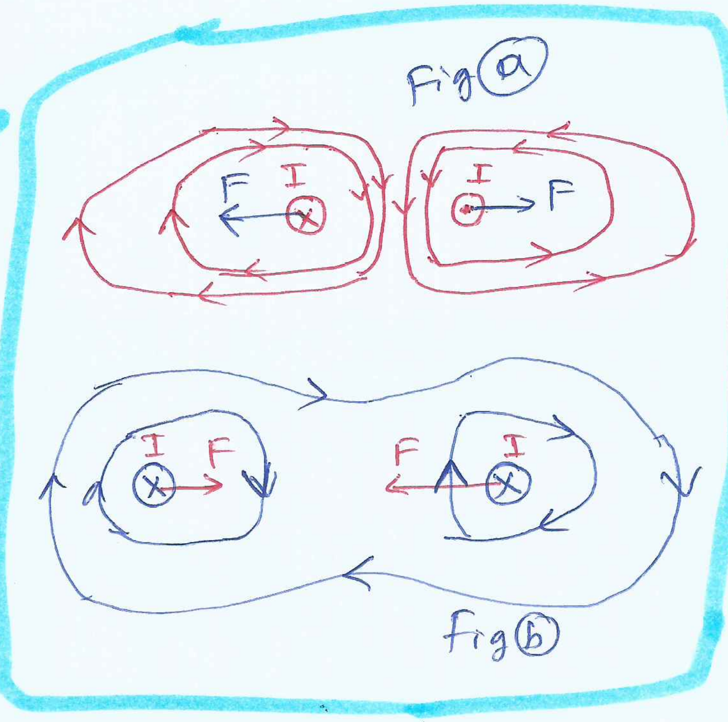
∴ $\boxed{\text{Torque} = 8.0 \times 10^{-4}\,Nm}$

Info

Force between Currents

Any electric current has a mag. field around it. If we have two currents, each will have its own mag. field, and we might expect these to interact.

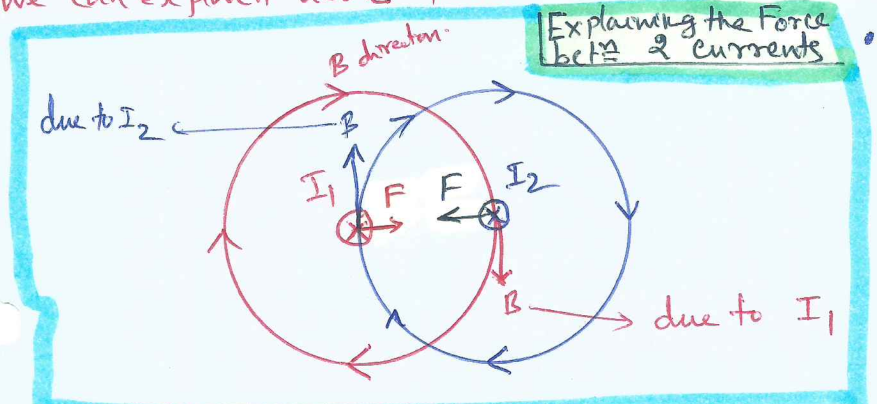
→ Fig ⓐ shows anti-parallel currents, one flowing into the page and the other flowing out of the page. Direction of $\vec{B}$ is as per RH Thumb rule and in fig ⓐ, there is an extra strong field in the space between the wires. ⟹ repulsive force on the two wires.



→ Fig ⓑ Shows the same idea, but for two parallel currents in the same direction and in the space left wires, the mag. fields cancel out. The wires are pushed together. ⟹ Attractive force on the two wires.

↓ We can explain above forces based on motor effect (Fleming LHR).

Explaining the Force betn 2 currents



- Consider I_1 → its mag. field lines at conductor I_2 is tangential as shown. So, as per FLHR, force on I_2 conductor due to I_1 is towards left.
- Similarly, consider I_2 → its mag. field lines at conductor I_1 is tangential as shown in figure. So, as per FLHR, force on I_1 conductor due to I_2 is towards Right

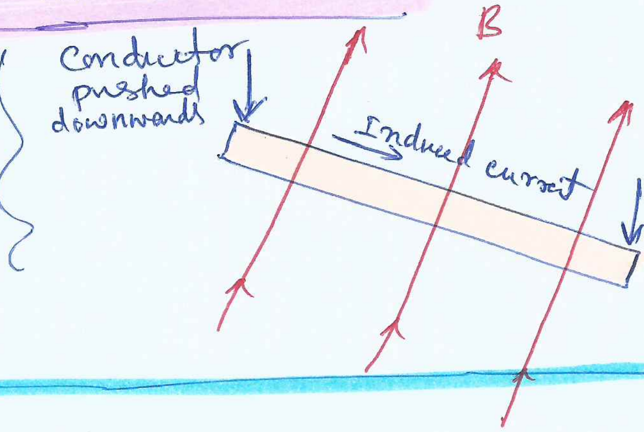
⟹ Attractive force ~~due~~ on the two wires.

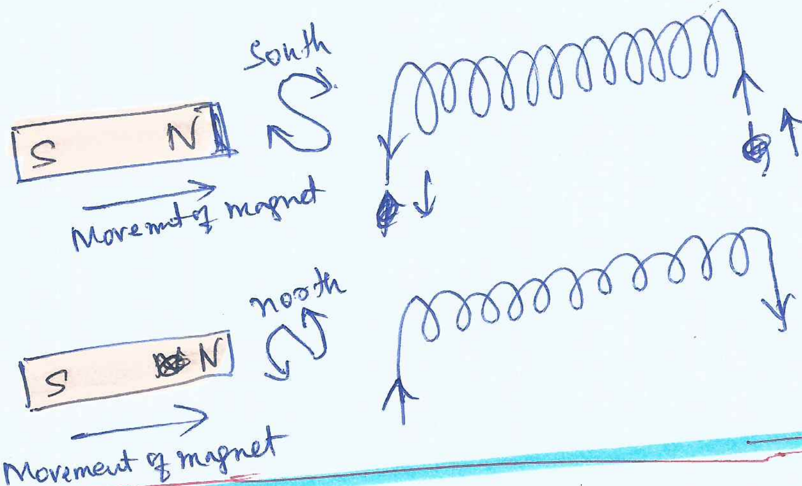
⟹ These are an example of an action and reaction pair, as described by Newton's third law of motion.

Info — 13 J —

Electromagnetic Induced Current direction.

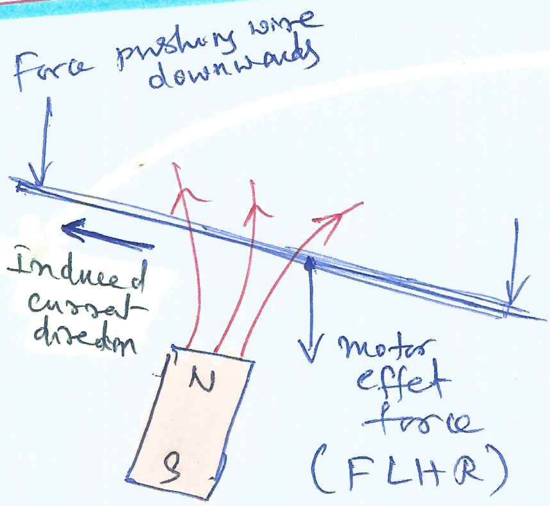
As per Fleming RHR.



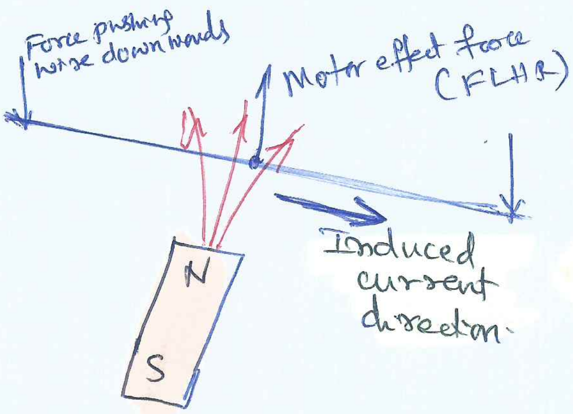


→ Incorrect

→ correct.



→ Incorrect



→ Correct

— 14 —

Induced Current and Induced charge.

If in a coil of N turns, the rate of change of magnetic flux be $\Delta \phi_B / \Delta t$, then the induced emf in the circuit is

$$\mathcal{E} = -N \frac{\Delta \phi_B}{\Delta t} \quad \text{(Faraday's law)}$$

If the coil is closed and total Resistance of its circuit be R, then the induced current in the circuit will be

$$\boxed{i = \frac{\mathcal{E}}{R} = \frac{N}{R} \frac{\Delta \phi_B}{\Delta t}} \longrightarrow (1)$$

eqn (1) indicates that the induced current in the circuit depends ~~on~~ upon the resistance (whereas induced emf is independent of resistance). ~~The char~~

The charge flowed through the circuit in a time-interval Δt will be given by

$$q = i \times \Delta t = \frac{N}{R} \frac{\Delta \phi_B}{\cancel{\Delta t}} \times \cancel{\Delta t}$$

$$\boxed{q = \frac{N}{R} \Delta \phi_B} \rightarrow (2) \quad = \frac{\text{no of turns} \times \text{change in magnetic flux}}{\text{Resistance}}.$$

Substituting $\Delta \phi_B$ in Weber, R in ohm, q will be in coulomb

EQ (2) shows that

→ the induced charge does not depend upon the time-interval. whether the change in magnetic flux be rapid or slow, the charge in the circuit will remain the same.

-15-

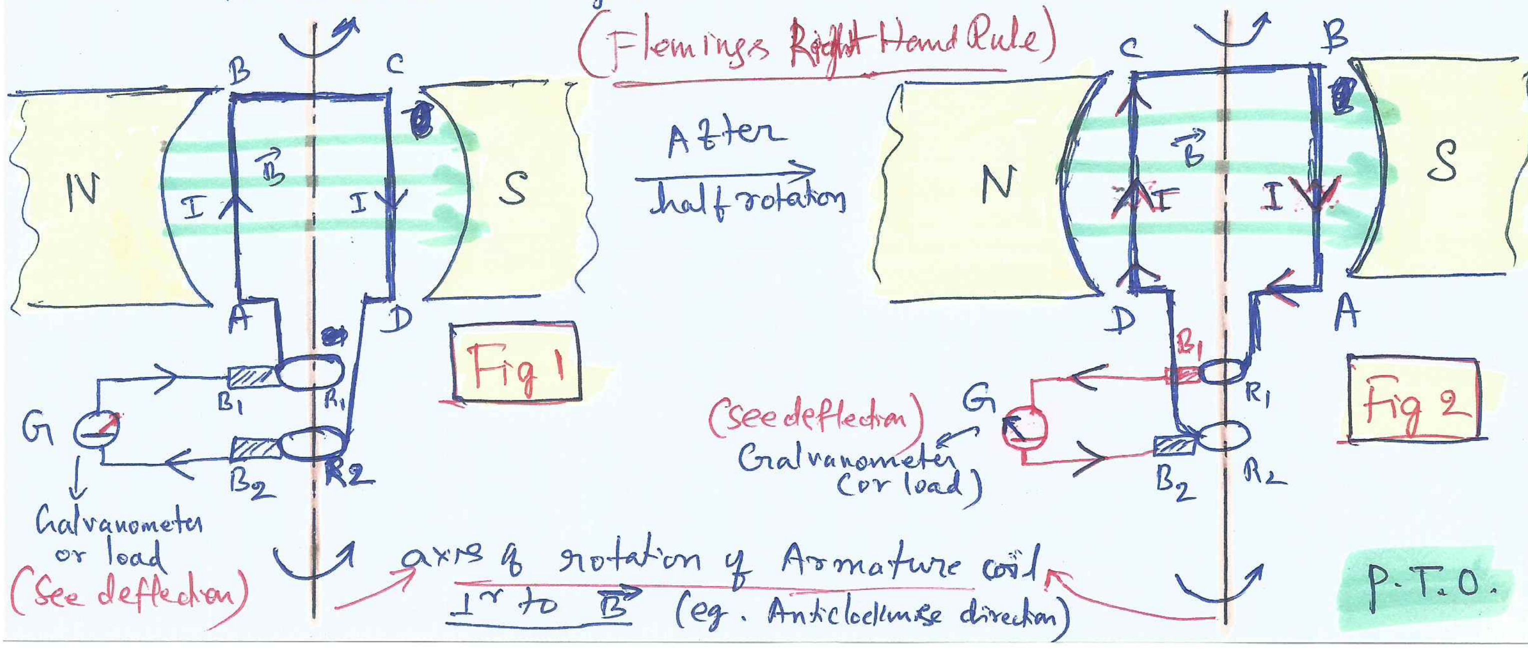
AC Generator (Alternator / A.C. Dynamo)

An exceptional application of e-m induction is the generation of alternating currents (ac). Although discovery of e-m induction is by Faraday, Tesla is credited with the development of the AC machine that converts mechanical energy into electrical energy. [Fleming's Right HR to Know direction of Current]

principle: It works on the principle of e-m induction i.e. when a coil is rotated in uniform magnetic field, an induced emf is produced in it. By changing the effective area of the coil (due to rotation) ~~& the magnetic field~~ exposed to magnetic field, there will be change in magnetic flux, resulting in generation of AC current.
In most AC generators, the coils are held stationary and the electromagnets are rotated resulting in AC generation. ~~in same~~

Construction: The main components of a.c. generator are
(i) **Armature**: Armature coil ABCD consists of large number of turns of insulated copper wire wound over a soft iron core.
(ii) **Magnet**: A strong permanent magnet or an electromagnet whose North and south poles are cylindrical in shape to produce magnetic field. The armature coil rotates betn pole pieces of the field magnet. The uniform mag. field provided by the field magnets is ⊥r to the axis of rotation of the coil.
(iii) **Slip Rings**: The two ends of the armature coil are connected to two brass slip rings R_1 & R_2. These rings rotate with the armature coil.
(iv) **Brushes**: Two carbon brushes (B_1 and B_2), are pressed against the slip rings. The brushes remain fixed while slip rings rotate alongwith the armature. These brushes are connected to the load through which the output AC is obtained.

(Flemings Right Hand Rule)



P.T.O.

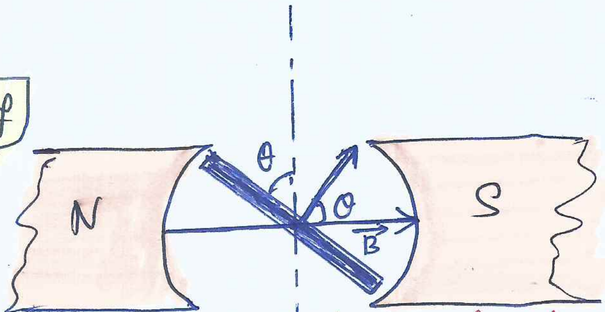
Contd. from page 15

Working :→ when the armature coil ABCD rotates (eg. using water, steam, wind etc) in the magnetic field provided by the strong field magnet, it cuts the magnetic lines of force. The magnetic flux linked with the coil changes due to the rotation of the armature and hence induced emf is setup in the coil. The direction of the induced emf or current in the coil is determined by Fleming's Right Hand Rule.

In Fig① (page15), current direction $ABCDB_2GB_1A$
In fig② (page15), current direction $DCBAB_1GB_2D$
} Assuming axis of rotation is anticlockwise.

→ So, the current flows through the load in one direction of half of revolution and in the next half revolution, the current flows through the load in the reverse direction. This process is repeated resulting in AC current.

Theory : Expression for Induced emf



- Let us start ~~timing~~ from the instant when the plane of the coil is $\perp^r$ to the field $\vec{B}$. In this position, the magnetic flux linked with the coil is maximum.
- Let coil be rotated anti-clockwise with a constant angular velocity ω, then the angle between normal to the plane of the coil and $\vec{B}$ at any instant t is given by

$$\theta = \omega t$$ ⇒ this implies the effective area of the coil exposed to mag. field lines changes with time.

- The component of mag. field normal to the plane of coil $= B\cos\theta = B\cos\omega t$
- Mag. flux linked with a single turn of the coil $= (B\cos\omega t)A$, where A is the area of ~~the~~ the coil.
- If the coil has N turns, then the total magnetic flux linked with the coil

$$\phi_B = N(B\cos\omega t)A = NBA\cos\omega t$$

- From Faraday's law, the induced emf is $\varepsilon = -\frac{d\phi_B}{dt}$

$$\varepsilon = -\frac{d}{dt}(NBA\cos\omega t) = -NBA(-\omega\sin\omega t)$$

$$\therefore \varepsilon = NBA\omega\sin\omega t$$

$f = 50\,Hz$ (India etc.)
$= 60\,Hz$ (USA etc.)

$$\therefore \boxed{\varepsilon = \varepsilon_0 \sin\omega t = \varepsilon_0 \sin(2\pi f t) \;;\; \text{where } \varepsilon_0 = NBA\omega} \longrightarrow (1)$$

Eq① gives the instantaneous value of emf and ε varies between $+\varepsilon_0$ and $-\varepsilon_0$ periodically (Since sine function varies between +1 and −1) 'f' is the freq. of revolution of generator's coil.

P.T.O.

Contd. from page 16

- Instantaneous current in the circuit having resistance R is given by

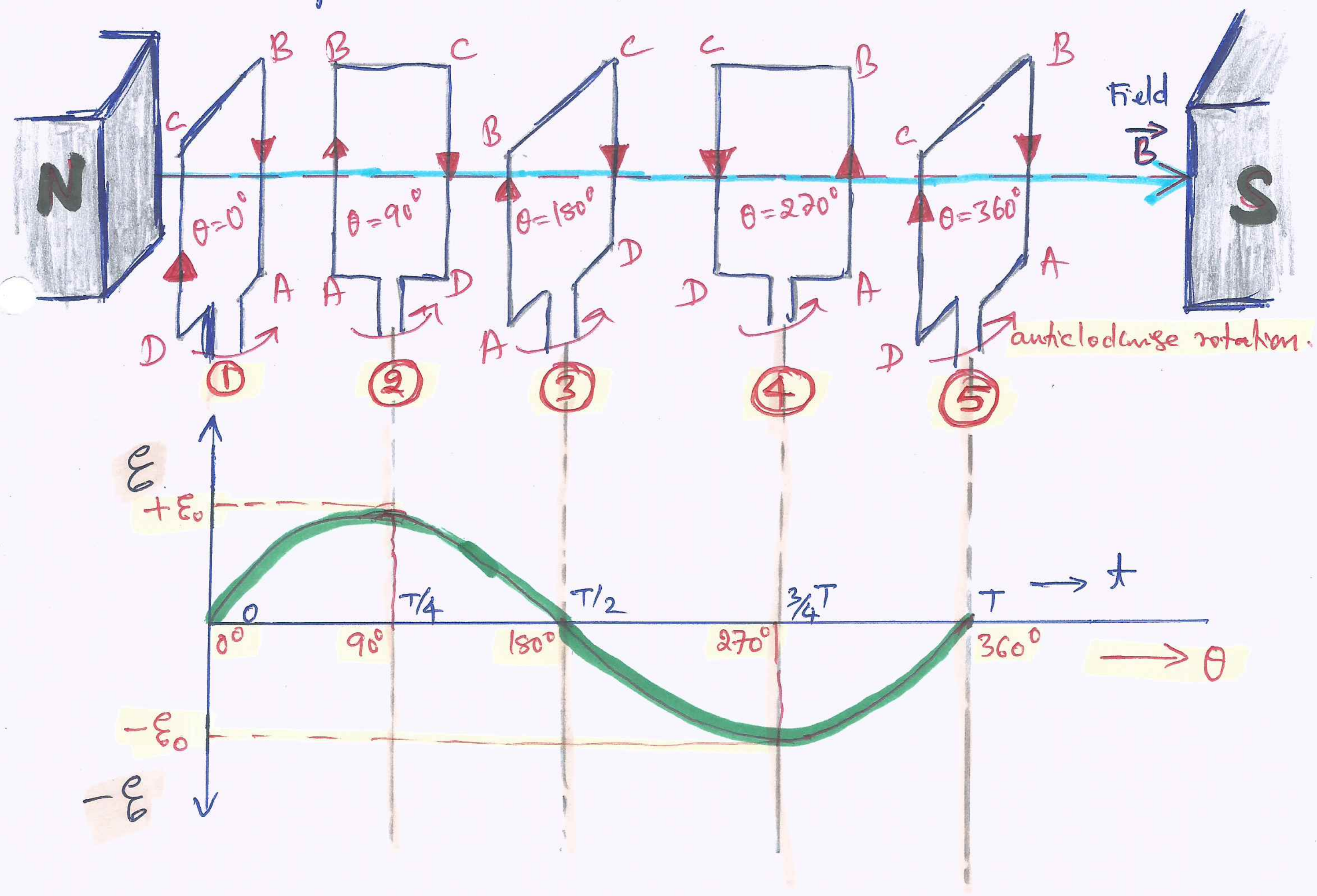
$$\boxed{I = \frac{\varepsilon}{R} = \frac{\varepsilon_0}{R}\sin\omega t} \longrightarrow (2) \qquad \boxed{I = \frac{\varepsilon_0}{R}\sin\theta}$$

- Variation of induced emf with different positions of the coil wrt the magnetic field. Note that θ is the angle between $\vec{B}$ and normal to the plane of the coil.

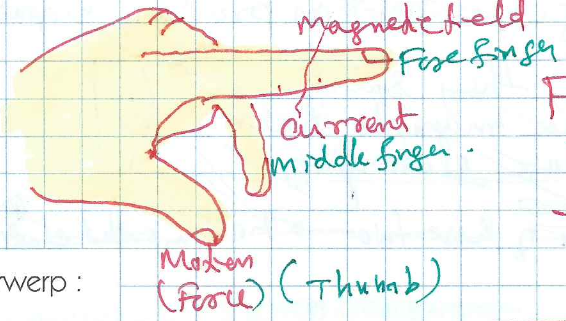
→ (1) when $\theta = 0°$ (the plane of coil is $\perp^r$ to $\vec{B}$), then $\varepsilon = 0$ ($\because \sin\theta = 0$)
→ (2) when $\theta = 90°$ (plane of coil is parallel to $\vec{B}$), then $\varepsilon = \varepsilon_0$ ($\because \sin 90° = 1$)
→ (3) when $\theta = 180°$ (plane of coil is $\perp^r$ to $\vec{B}$), then $\varepsilon = 0$ ($\because \sin 180° = 0$)
→ (4) when $\theta = 270°$ (plane of coil is parallel to $\vec{B}$), then $\varepsilon = -\varepsilon_0$ ($\sin 270° = -1$)
→ (5) when $\theta = 360°$ (plane of coil is $\perp^r$ to $\vec{B}$), then $\varepsilon = 0$ ($\sin 360° = 0$)

Thus, when $\theta = 90°$ or $270°$, the induced emf has extreme values (in opposite direction), as the change of flux is greatest at these points. The direction of current changes periodically and hence current is called alternating current (ac).

→ See below figure.



End of AC Generator



Fleming's Left Hand Rule.

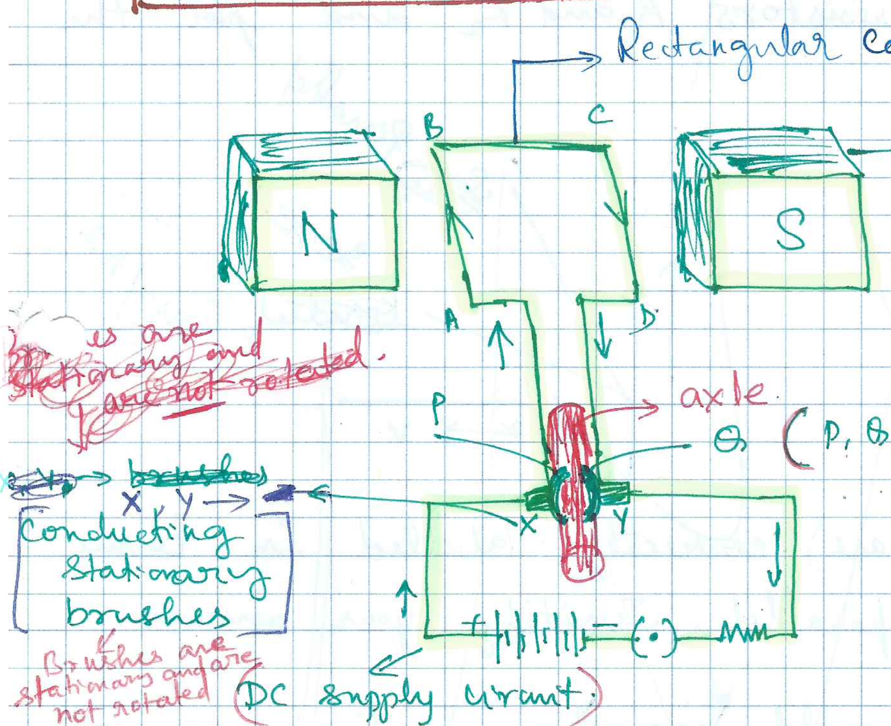
Electrical energy → Mechanical ~~ene~~ Energy

Datum

Onderwerp :

DC Electric Motor

[Armature] = {Soft iron core + Coil wound on that core ~~coil wound on that core~~}



→ Split ring also rotates with axle (shaft)

(P, Q → Split rings (commutator)
- inner surface insulated ~~and~~
- fixed to axle
- outer surface conducting ~~and~~
- makes contact with ~~conducting~~ conducting brushes.

- The direction of current is shown in figure.
- Current via ~~AB~~ arm AB is from A → B, in arm CD, ~~it is C→D~~ it is C→D
- Therefore, according to Fleming's LHR, arm AB is pushed down, arm CD is ~~pushed up~~ pushed up
- So the coil experiences half-rotation in anticlockwise direction.
- Now split ring "P" makes contact with brush Y and Q with ~~brush~~ brush X
- So current is reversed ~~and~~ and flows along the path DCBA
- Now DC experiences force down, and arm AB experiences ~~force up~~ force up
- This continues and the coil (and the axle) rotates continuously ~~in the~~ in the anti-clock wise direction (Reverse battery polarity to result in clockwise ~~rotation~~ rotation)

Uses: Electric motors are used in electric fans, refrigerators, mixers, washing machines, water pumps

Principle: The fundamental principle is that ~~the~~ a current-carrying ~~carrying~~ conductor experiences a mechanical force when ~~placed~~ placed in a magnetic field.

DC Generator (DC Dynamo)

Fig (1)

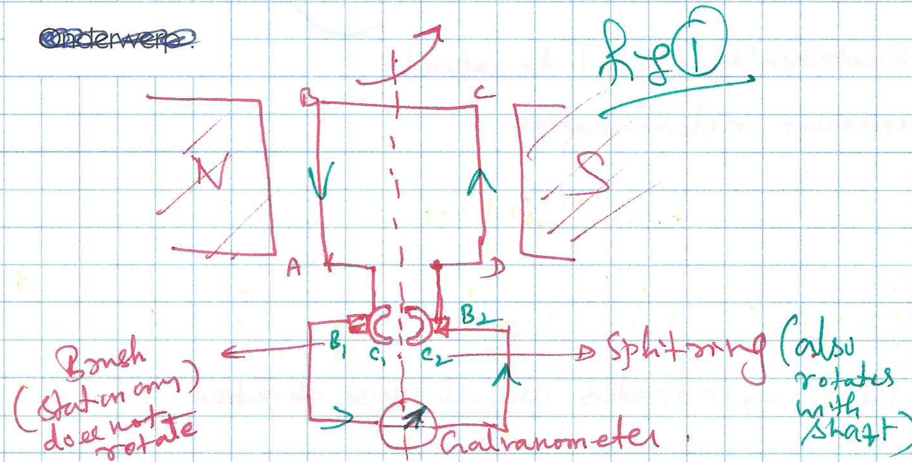
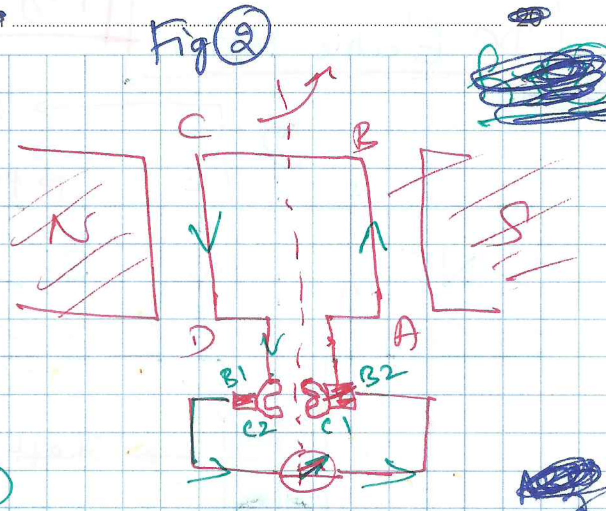


Fig (2)



- DC generator uses split-ring commutator with brushes B_1 and B_2 making contact, an external circuit to indicate the induced current, a coil ABCD placed in a strong magnetic field. The shaft is rotated anticlockwise (or clockwise).
- Arm AB moves down, arm DC moves up, induced current is in direction DCBA. Galvanometer shows the deflection.
- After half rotation, split-ring C2 makes contact with brush B1 and split-ring C1 makes contact with B2.
- Now AB moves up, arm DC moves down, current flows through ABCD, which is in the same direction as fig (1), thus generating DC current.

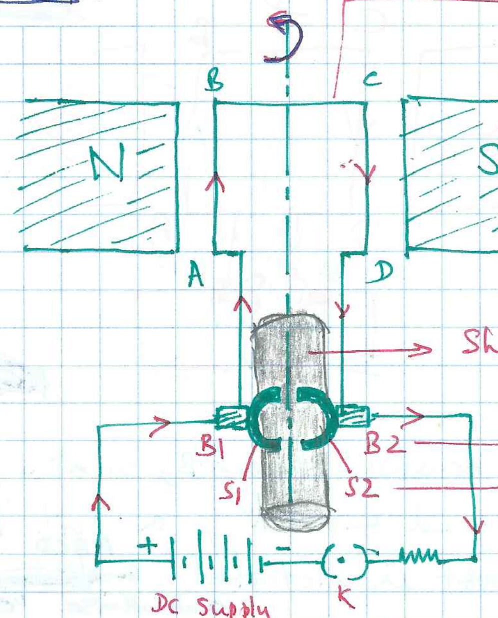
Principles → Electromagnetic induction: when a rotating coil cuts magnetic lines of force (make and break of magnetic flux), an emf (current) is induced in the coil. Using split-ring commutator, DC current can be generated.

~~Figures~~

Figures

DC Electric Motor

~~Underwear~~:



→ Rectangular coil [Armature]

→ permanent or electro-magnet

Shaft (Axle) → rotates anti-clockwise direction.

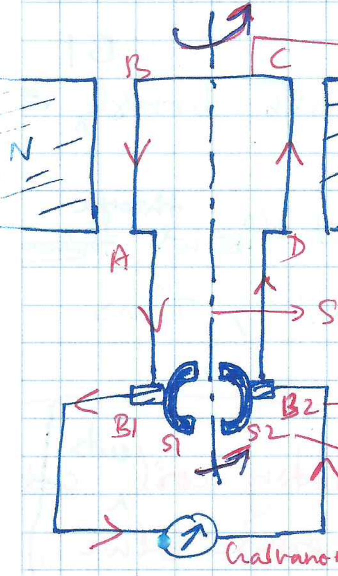
→ Brushes stationary, don't rotate with shaft

→ Split ring commutators rotates with Axle.
(Split ring – inner surface → insulated
outer surface → conducting)

DC Generator ~~DC Generator~~ (DC Dynamo)

after half rotation.

Fig 1 → Fig 2



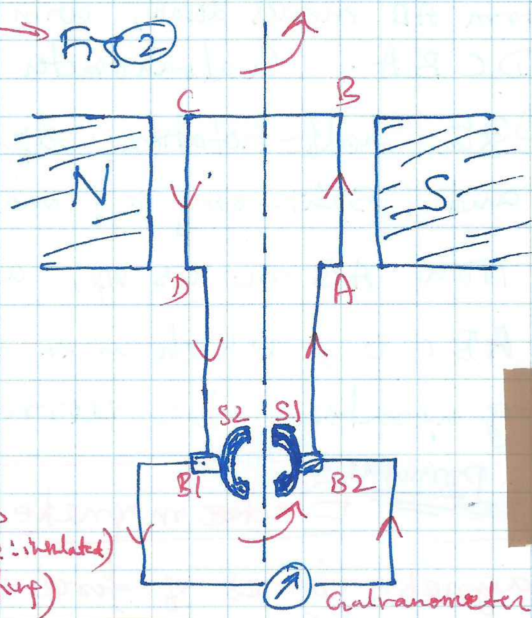
→ Rectangular coil (armature)

→ permanent or electromagnet.

→ Shaft (Axle) rotated in anticlockwise direction

B2 → Brushes stationary don't rotate with Axle (shaft)

→ Split rings commutators rotates with axle (Inner surface of Axle: insulated)
outer surface of axle → (conducting)

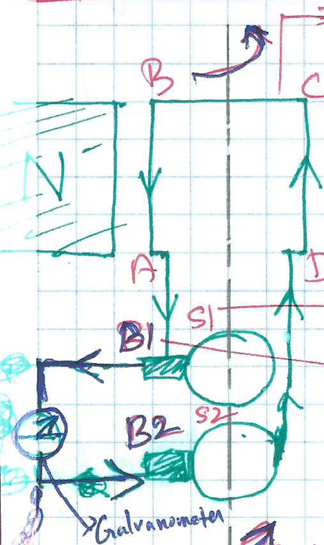


~~AC~~ AC Generator (AC Dynamo)

→ Rectangular coil (Armature)

→ permanent or electro-magnet

Fig 1 ~~After~~ half rotation → Fig 2

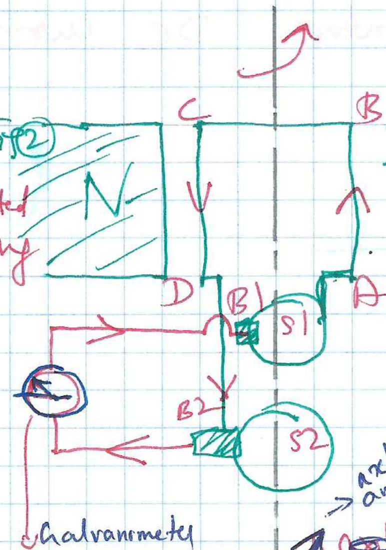


Inner Surface → Insulated
Outer Surface → Conducting

→ Slip rings (not split)
rotates ~~with~~ with axle

→ Brushes (conducting)
Stationary, don't rotate with axle.

axle rotated in anti-clockwise ~~clockwise~~ direction.



→ axle rotated in anticlockwise direction

~~axle rotated in anti-clockwise direction~~

~~Galvanometer~~

(Q) A student performs an experiment to study the magnetic effect of current around a current carrying straight conductor. He reports that

(i) the direction of deflection of the N-pole of a compass needle kept at a given point near the conductor remains ~~constant~~ unaffected even when the terminals of the battery sending current in the wire are inter-changed

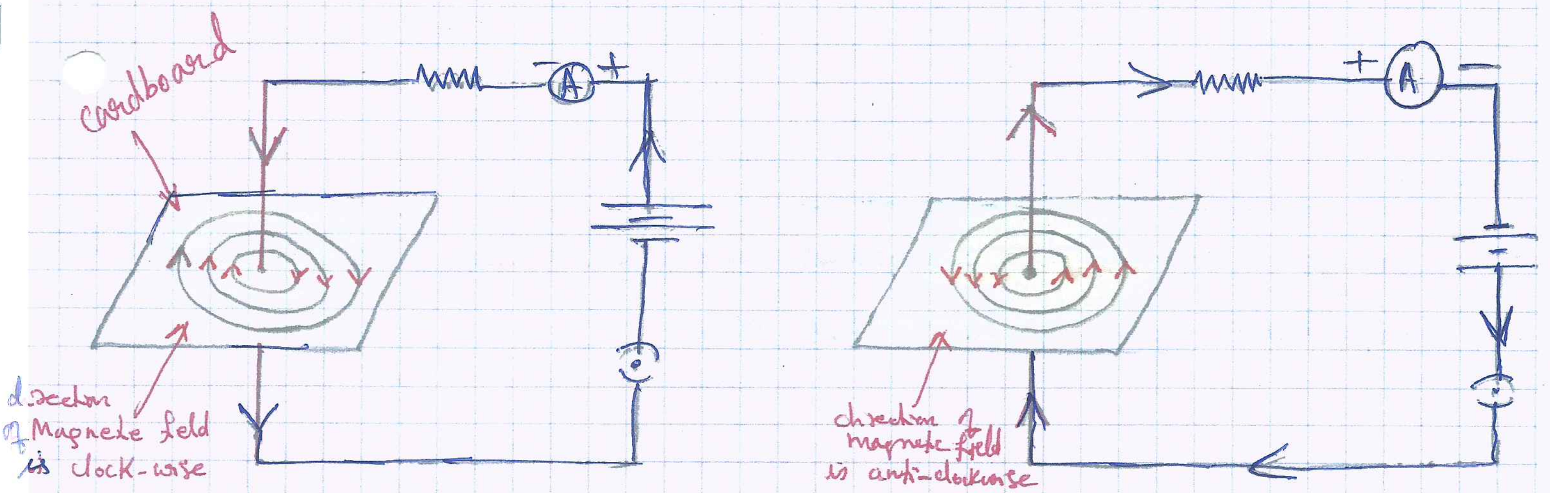
(ii) for a given battery, the degree of deflection of a N-pole decreases when the compass is kept at a point farther away from the conductor.

Which of the above observations of the student is incorrect and why

Answer: (i) is incorrect, since as per the "Right hand Thumb rule" or "Maxwell's corkscrew rule", the ~~direction of magnetic field lines (field)~~ of the deflection of N-pole of compass needle (indicates the direction of magnetic field) should reverse when the direction of current is reversed.

For your study :→

Magnetic field around a Current Carrying Straight conductor.

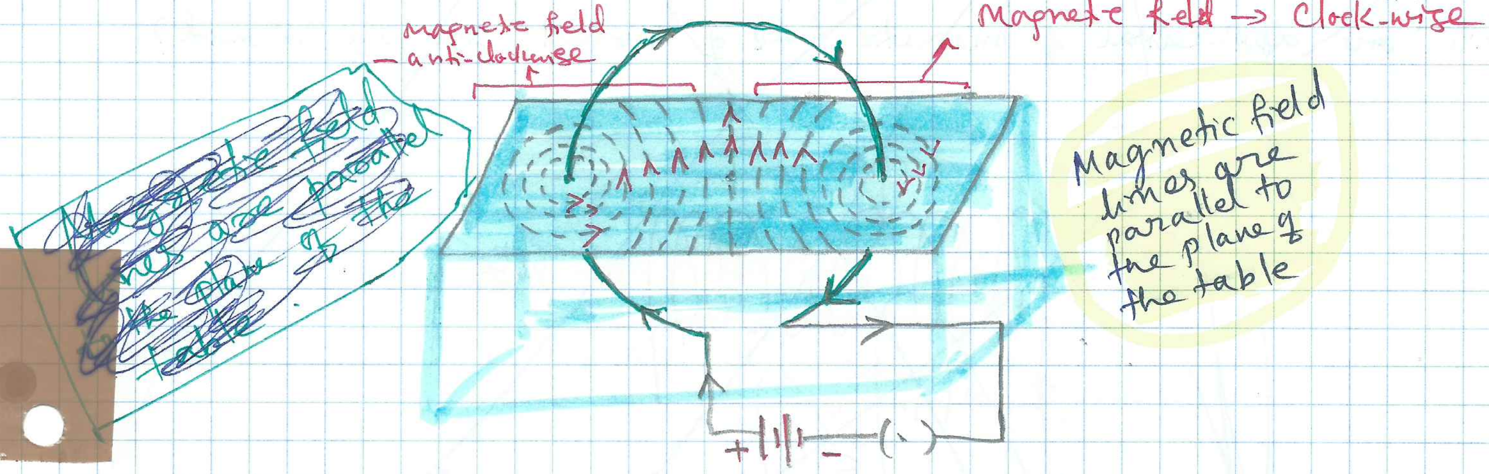


- When a compass needle is placed at any point on the cardboard, the direction of N-pole of the compass needle would give the direction of the magnetic field.
- The magnetic field lines in any plane are concentric circles with the current carrying conductor passing through their common centre, So, it can be imagined that a current carrying conductor is surrounded by a cylindrical shell of magnetic flux lines.

(For your study)

Onderwerp :

Magnetic field due to a current carrying circular wire .

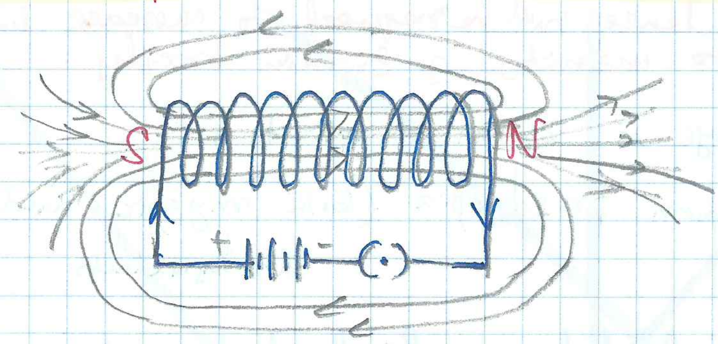


The field lines in a current carrying circular coil have the following Characteristics

1. Field is $\perp^r$ to the plane of the coil
2. circular near the wire
3. Straight at the Centre
4. Direction of magnetic field is as per Right hand Thumb Rule .

(For your Study)

Magnetic field due to a current in a Solenoid



A coil of large number of turns closely wound on a hollow cylinder of insulated ~~insulated~~ material or otherwise is called a Solenoid.

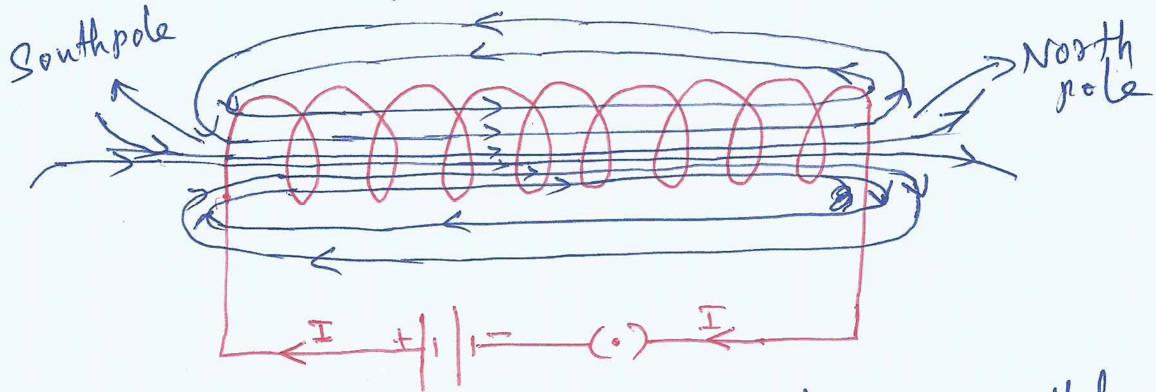
1. The end of the solenoid having clockwise current will act as S-pole →(field enters into)
2. The end of the solenoid having anti clockwise current will act as N-pole ↳(field comes out)
3. ~~So~~, Thus , a solenoid acts as a normal magnet .
4. ∴ outside the solenoid → field direction is N → S
   Inside the solenoid → field direction is S → N
5. Inside the Solenoid, the field lines are parallel, hence indicating a uniform magnetic field . ∴ the magnetic field inside a long straight solenoid - carrying current is the same at all points
6. The strength of the magnetic field inside the solenoid is directly $\propto^{l}$ to
   (a) number of turns per unit length of the solenoid (b) the current passing through.
7. Application :→ Used in the manufacture of electro magnets and permanent magnets when the material is placed inside current carrying solenoid , it will get magnetised .

Imp Info:
A bunch of nails or an iron rod placed inside the solenoid, they will become electro-magnets. Once the current is put-off, the magnetic field is also lost. Such magnets are called Electro-magnets.

If the materials like carbon steel, chromium steel, tungsten ~~steel~~ ~~steel~~ steel and some alloys are magnetized using solenoid, they become permanent magnets (will not lose magnetic property even if current is removed).

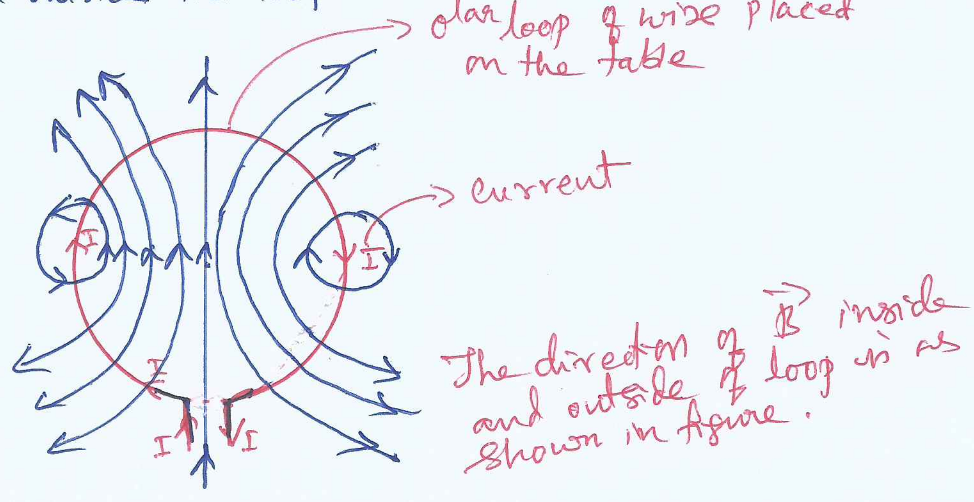
problem: Draw the pattern of magnetic field lines of a current-carrying solenoid. What does the pattern of field lines inside the solenoid indicate? Write one application of magnetic field of current-carrying solenoid?

Ans:



- The field lines inside the solenoid are parallel indicating uniform magnetic field.
- The application is to produce electro-magnets and permanent magnets.

problem: Consider a clar loop of wire lying in the plane of the table. Let the current pass through the loop clockwise. Apply Right hand rule to find out the direction of magnetic field inside and outside the loop.



IMP -24- $\boxed{-24-}$ Motional EMF

$\boxed{\text{Motional EMF}}$

From Faraday's law, induced emf is given by

$$\mathcal{E} = -N\frac{d\phi}{dt}\text{, where}$$

mag. flux $\phi = BA\cos\theta$.

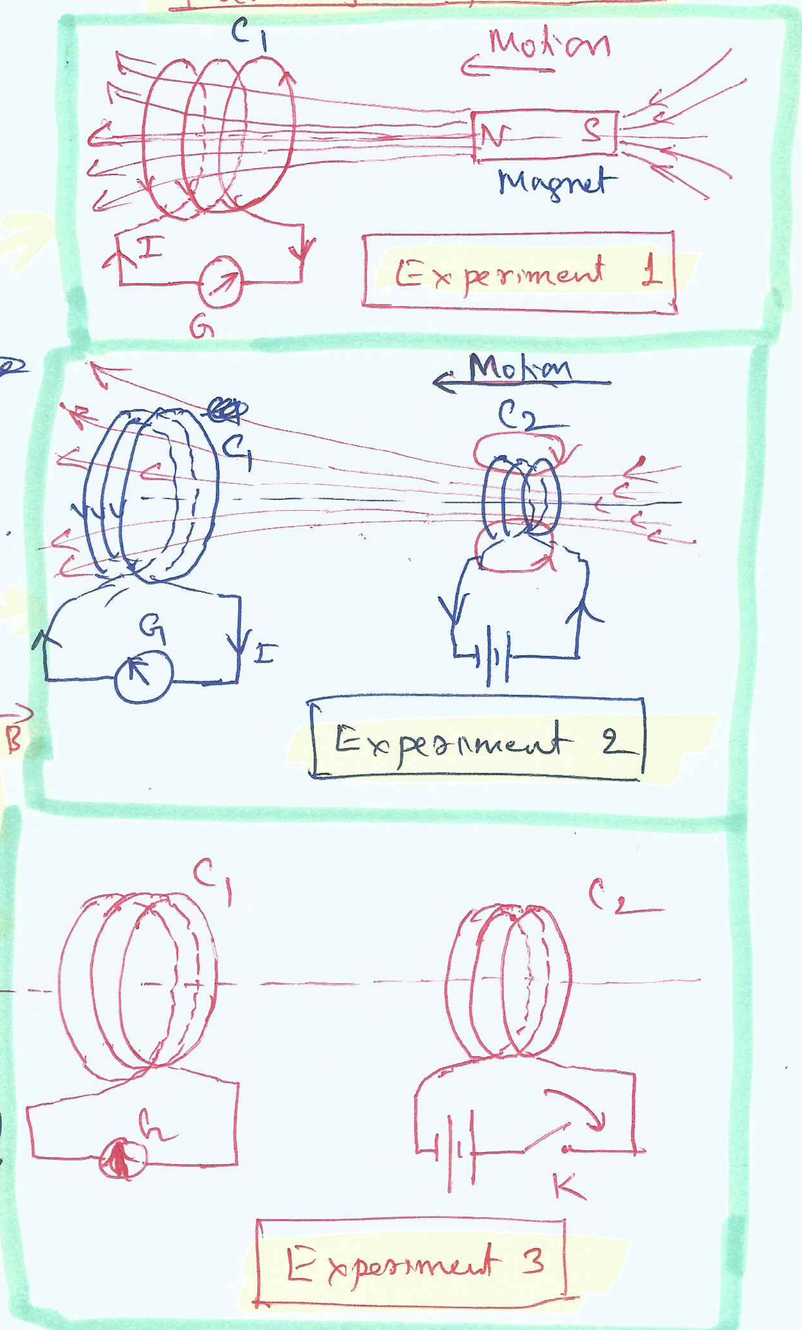
This shows induced emf $\mathcal{E}$ ~~can be~~ ~~changed~~ depends on

(a) no. of turns N of coil
(b) Rate of change of mag. flux.

Also, Magnetic flux can be changed by

(i) changing the strength of mag. field B
(ii) changing the orientation (θ) of the coil wrt the magnetic field (See AC Generator) is the basis of this)
(iii) changing the area A of the coil.

Faraday's experiments:



- Faraday's 3 experiments are corresponding to point (i), so change in magnetic field or flux
- AC Generator concepts prove point (ii) by changing θ.

~~what is left is change in area A of coil~~

- The common point in all 3 experiments by Faraday is that the time rate of change of magnetic flux through the circuit induces emf in it.
- What is left is Change in area A of the coil

changing Area A $\Rightarrow$ Changing mag. flux enclosed by the circuit (total no. of mag. lines of force within the circuit)

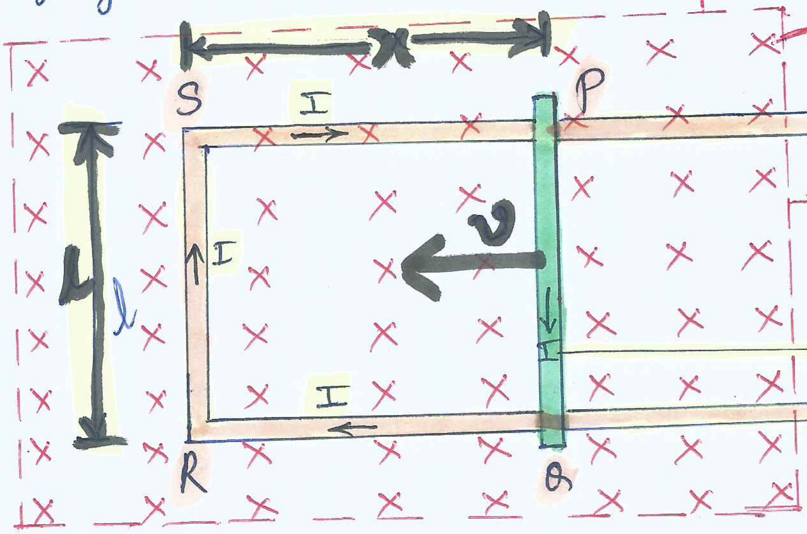
Motional emf. $\rightarrow$ Induced emf produced by changing the area of a closed circuit by the movement of the circuit or part of it through a uniform mag. field is known as motional emf.

P.T.O

IMP

Motional EMF (Induced EMF by changing the Area)

The following experiment shows that it is possible to produce induced emf (or current) by moving the conductor instead of varying the magnetic field.



- The U-shaped conductor SMNR and slidable rod PQ is placed in a mag. field $\vec{B}$, which as in figure is uniform and time-independent and directed downwards ⊥ʳ to plane of paper.
- Let conducting rod PQ be moved LEFT with a constant velocity v within the limits of magnetic field as shown in figure. Assume that there is no friction on the arms of the U-shaped stationary conductor.
- PQRS forms a closed circuit enclosing an area that decreases as PQ is moved left. This results in decrease in mag. flux in the loop PQRS.
- The flux enclosed by the loop PQRS is

$$\phi_B = B \cdot A = Blx \longrightarrow (1) \quad (\because lx \text{ is area of loop PQRS}) \quad (\cos 0 = 1)$$

In eqⁿ (1), B and l are constants, whereas x decreases with time linearly. ∴ As per Faraday's law, rate of change of flux ϕ_B is

$$\epsilon = -\frac{d\phi_B}{dt} = -\frac{d}{dt}(Blx) = -Bl\frac{dx}{dt} = Blv$$

$$\therefore \boxed{\epsilon = Blv \quad (\text{where } v = -dx/dt)} \longrightarrow (2)$$

- The induced emf, thus produced, is called "motional emf". The emf Blv sets up a current in the loop PQRS given by

$$\boxed{I = \frac{\epsilon}{R} = \frac{Blv}{R}} \longrightarrow (3)$$

where R is the resistance of the loop PQRS.

- Note that ~~eqⁿˢ (2) and (3)~~ the only dimension of the loop (i.e. l) that enters into equations (2) and (3).
- To find the direction of the induced current in loop PQRS, we will use Lenz's law.

P.T.O. → contd.