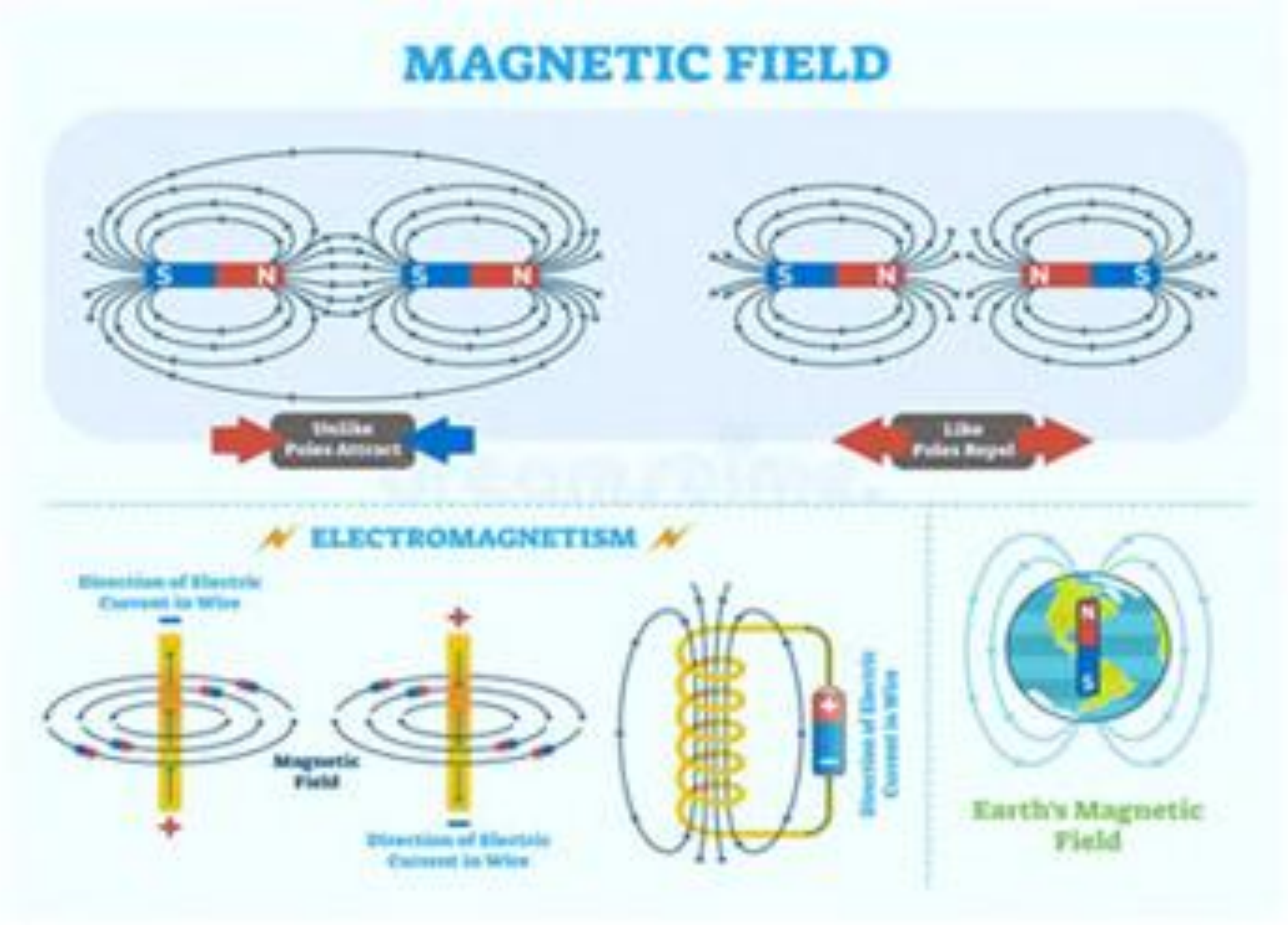
G - 12
U – 4
Physics short Notes


MAGNETIC FIELD
S
N
S
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Unlike Poles Attract
S
N
N
S
Like Poles Repel
ELECTROMAGNETISM
Direction of Electric Current in Wire
−
+
Magnetic Field
+
−
Direction of Electric Current in Wire
+
−
Direction of Electric Current in Wire
N
S
Earth's Magnetic Field

Introduction

Brainstorming Questions

1. List some of electric current effects.
2. Why do electricity & magnetism appear related?
3. Explain how current in a wire produces magnetic effect?

Unit 4 Electromagnetism

- Electromagnetism combines electricity and magnetism, also known as the electromagnetic force.
- Electromagnetic Fields: created by interactions between electric charges and magnetic fields.
  - ✓ electromagnets: generate these fields using electric current.

Key Discoveries:

Oersted (1819): Electric current affects a compass needle.

Faraday & Henry (1820s): Changing magnetic fields induce electric currents.

Maxwell’s Contribution: Showed that changing electric fields create magnetic fields and vice versa.

Importance: Enabled the development of technologies such as radios, TVs, computers, and electric motors.

Applications: Covers forces on moving charges and current-carrying conductors in magnetic fields.

4.1 Magnets and Magnetic Fields

Brainstorming Questions

1. Differentiate between magnetic poles & describe their interactions.
2. What is an electromagnet? How is it different from permanent magnet?
3. What are magnetic domains? How is it different from a permanent magnet?
4. What is magnetic field? How can it be visualized?

Unit 4 Electromagnetism

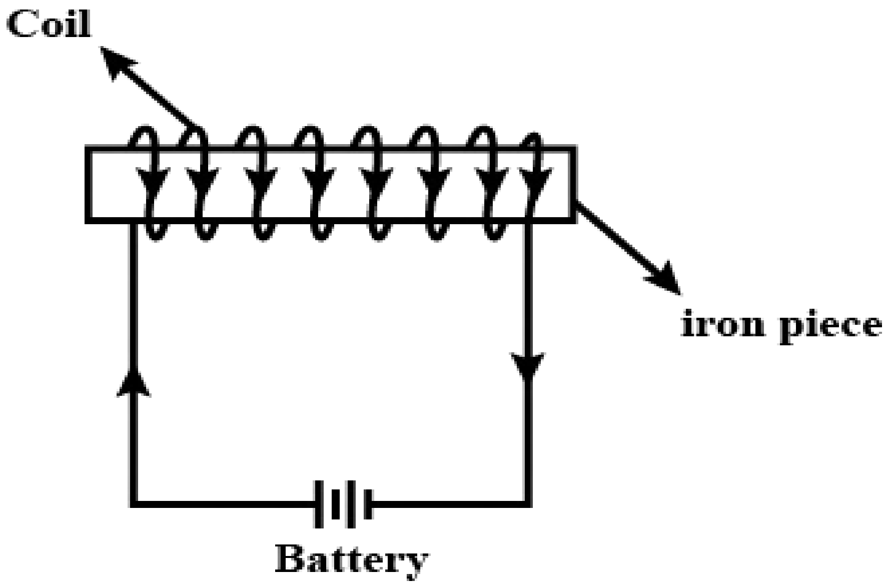
Magnetic Field Origin: A magnetic field is generated by moving electric charges or magnetic materials like magnets.

Cutting a Magnet: Cutting a bar magnet always results in two smaller magnets, each with a north and south pole-magnetic poles can't be isolated.

Types of Magnets:

Permanent Magnets: Retain their magnetic properties due to the material's internal structure (intrinsic properties).

Electromagnets: Generate magnetic fields when electric current flows through a coil of wire; lose magnetism when the current stops.

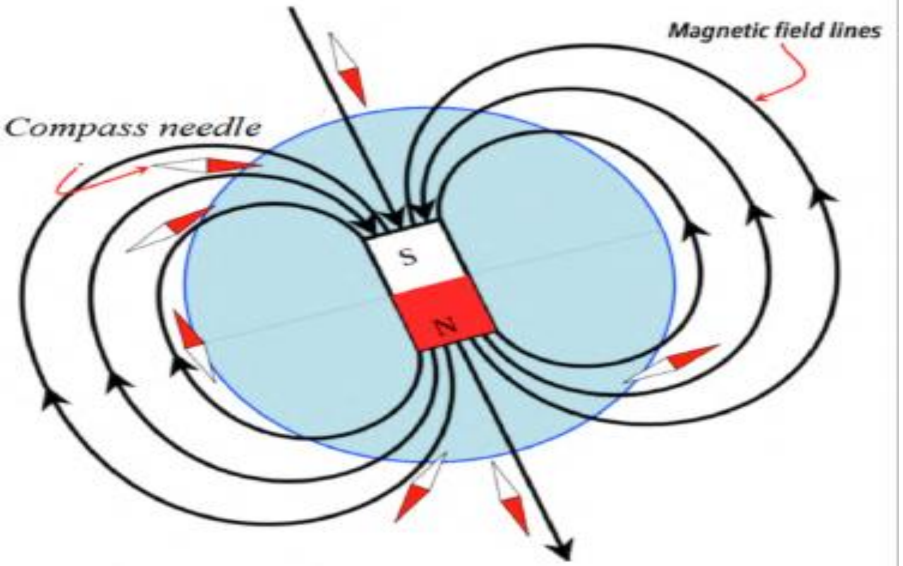


electromagnet.mp4

✓ The iron core serves to increase the strength of the magnetic field created.

Earth's Magnetic Field: Acts like a giant bar magnet with magnetic poles near the geographic poles, aligning compass needles with it.

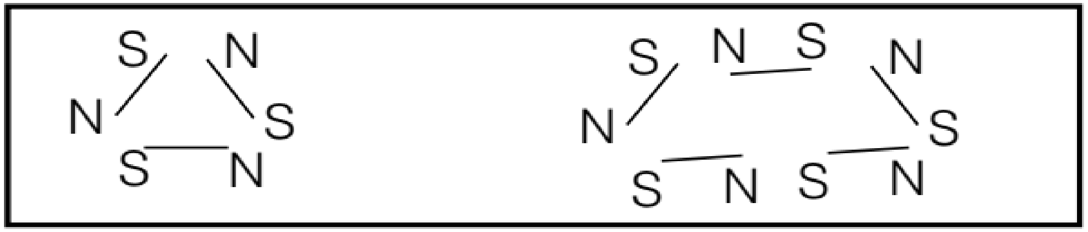
- This earths magnetic field, enables compasses to show you which way is north.
  - ✓ *A compass needle is like a small suspended bar magnet. Its north seeking pole will point to the earths magnetic south pole(near Earth's geographical north pole). If you know which direction is north, then you can line up a map correctly to find your way through unfamiliar areas.*



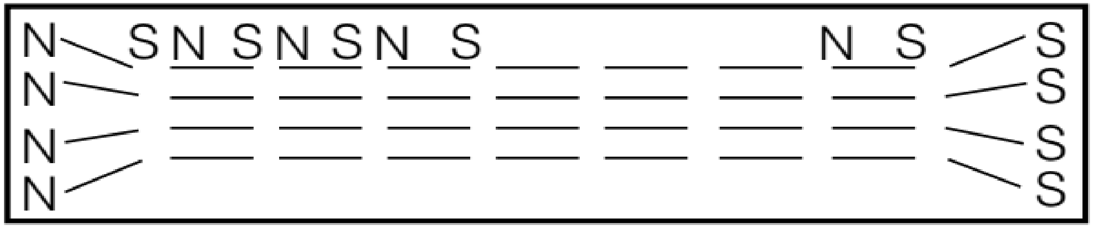
Earth's Magnetic Field.mp4

Magnetic domains:

- ✓ small regions in magnetic materials with aligned invisible small magnets.
- ✓ random orientation in unmagnetized materials cancels out net magnetism.



- ✓ align in the direction of an external magnetic field during magnetization.



MAGNETIC DOMAINS ANIMATIONS.mp4

Magnetization

- ✓ **is process of aligning magnetic domains in a material.**
- ✓ **produce a net magnetic effect in the presence of an external magnetic field.**

Magnetic shielding

- ✓ reduces or blocks external magnetic fields.
- ✓ achieved using materials with high permeability (like: sheet metal, metal foam and plasma (ionized gas)).
- ✓ protects devices like MRI machines, cathode ray tubes, and electronic sensors.

Unit 4 Electromagnetism

Magnetic Field: The region around a magnet or moving charge where magnetic forces are exerted.

- ✓ *Magnetic fields are vector quantities (points in the direction that a compass would point) and form closed loops.*

Electric vs. Magnetic Fields:

Electric Field: Exists around charges; lines start at positive and end at negative charges (do not form a loop).

- produced by a unit pole charge, i.e., either by a positive or through a negative charge.

SI unit: (Newton/Coulomb)

Magnetic Field: Exists around magnets and moving charges; lines form closed loops.

- caused by a dipole of the magnet (i.e., the north and south pole).

SI Unit: (Tesla)

4.2 Magnetic Field Lines

1. What are magnetic field lines? Why are they useful in understanding magnetic fields?
2. Why do magnetic field lines never cross each other?
3. How do magnetic field lines indicate the strength and direction of magnetic field?
4. Why do magnetic field lines form a closed loop?

Magnetic Field Lines are:

- ✓ Imaginary lines used to represent magnetic fields; their density indicates field strength.
- ✓ Direction is tangent to the lines, with field strength proportional to line closeness.

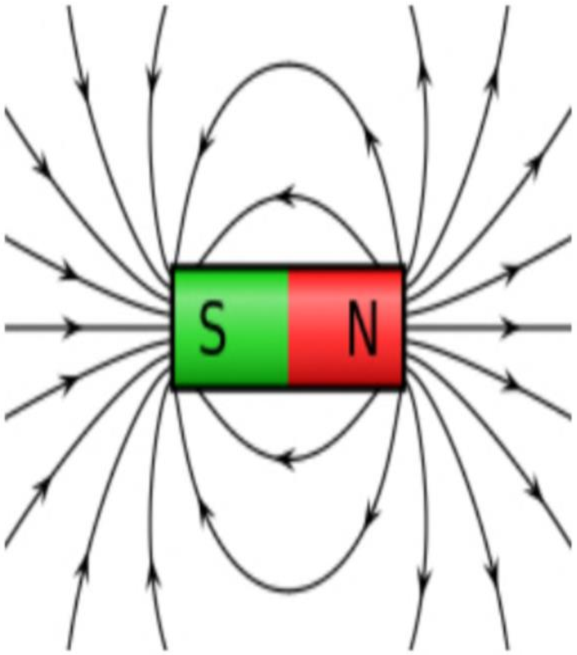
Properties:

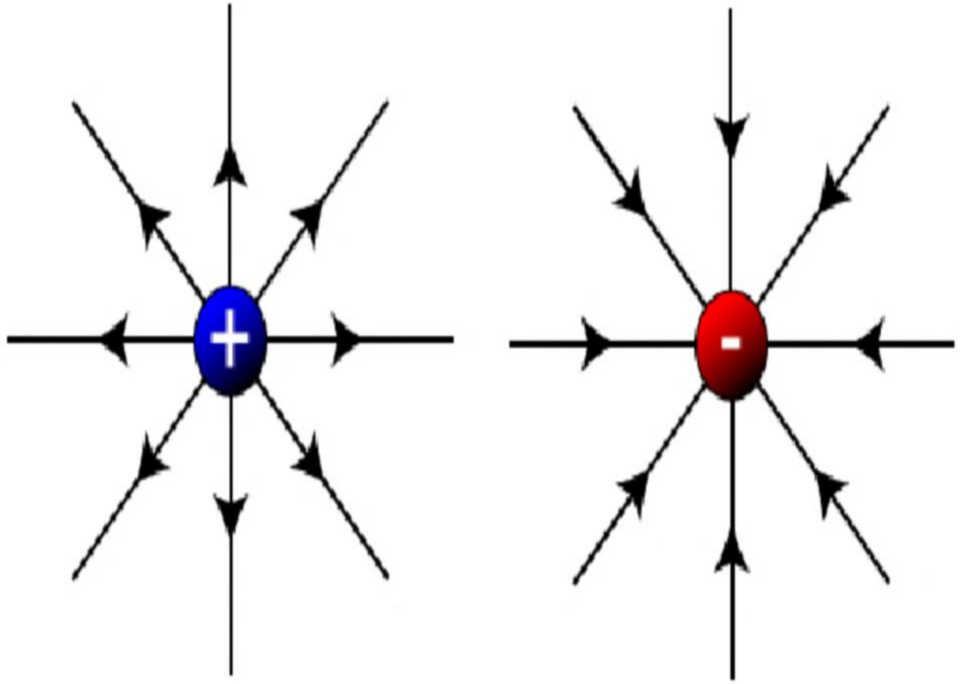
- ✓ Magnetic field lines are continuous, forming closed loops without a starting or ending point.
- ✓ Lines emerge from the north pole and merge at the south pole, returning inside the magnet from south to north.
- ✓ Magnetic field lines never cross, ensuring the field is unique at each point.

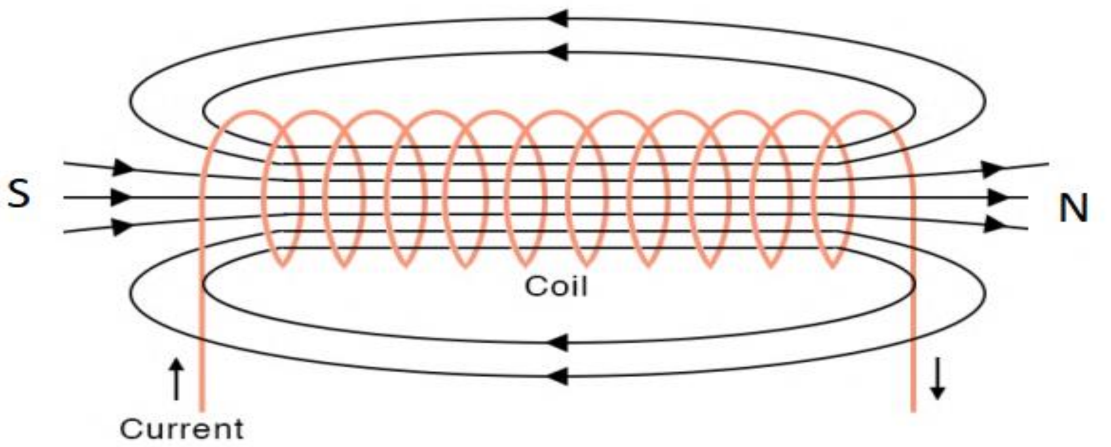
Activity!

1. Explain the direction and significance of magnetic field lines.
2. Sketch the magnetic field lines around two bar magnets placed close to each other with like pole facing.

Unit 4 Electromagnetism







Visual Representation:

✓ Iron filings align along field lines, showing the magnetic field pattern around magnets.

field lines.mp4

a) Magnetic field pattern surrounding a bar magnet b) Magnetic field pattern between opposite poles (N–S) of two bar magnets and
c) Magnetic field pattern between like poles (N–N) of two bar magnets.

4.3 Current and Magnetism

Brainstorming questions

1. What happens to a magnetic compass when it is placed near a current - carrying wire?
2. What happen to the magnetic field strength;
    a) If you increase the current in the wire?
    b) If you wound the wire into a number of turns?
3. How does the distance from a current-carrying wire affect the strength of magnetic field?

Relationship Between Current and Magnetism:

- ✓ A current-carrying conductor produces a magnetic field, demonstrated by the deflection of a compass near the wire.

current-carrying wire.mp4

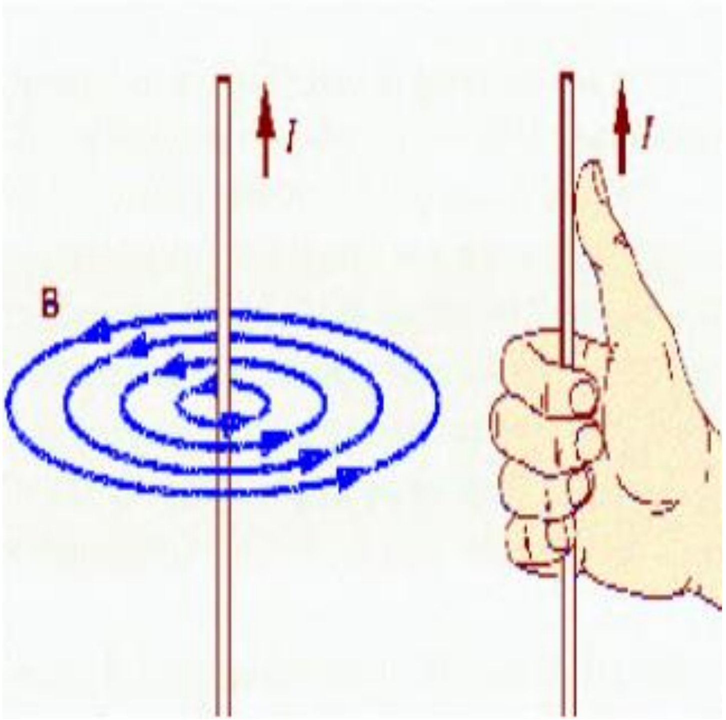
- ✓ The magnetic field exists only while the current flows.

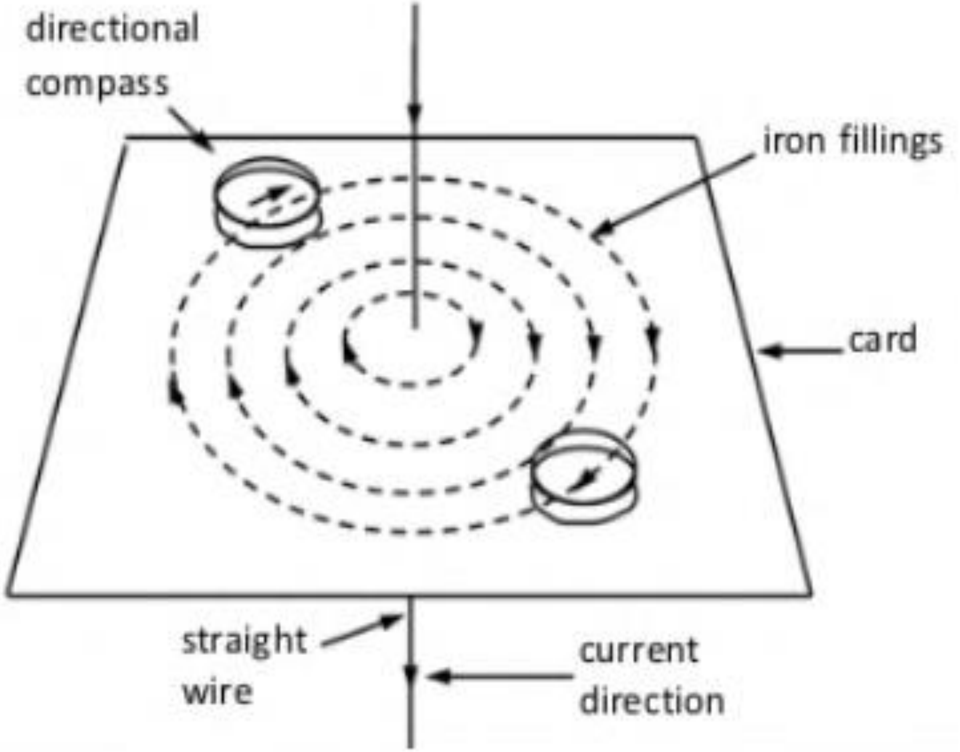
Magnetic Field Around a Straight Current-Carrying Wire:

- ✓ Magnetic field strength increases with current and decreases with distance from the wire.
- ✓ Field lines form circular patterns around the wire and reverse when the current's direction is reversed.

Fleming's Right-Hand Rule:

- ✓ Thumb points in the direction of current, and fingers curl in the direction of the magnetic field lines.





How Does an Electromagnet Work_ .mp4

The characteristics of the magnetic field produced by a current flowing in a straight wire have the following properties.

- ✓ The magnetic field lines form a circular pattern.
- ✓ The magnetic field strength increases when current increases.
- ✓ The magnetic field strength is stronger near the wire and weaker further away.
- ✓ When the direction of the current is reversed, the direction of the magnetic field is reversed too.

Activity!

A current flows through a vertical wire. What is the direction of the magnetic field at a point north of the wire?

Ampere's Law:

- ✓ *States that the magnetic field around an electric current is proportional to the current, and the total field is the vector sum of all fields of segments of current.*

Magnetic Field Formula:

Ampere's Circuital Law .mp4

$$B = \frac{\mu_0 I}{2\pi r} \text{ (for long straight wire)}$$

where; ($\mu_0 = 4\pi \times 10^{-7}$ T.m/A) is permeability,
(I) is current, and (r) is distance).

- ✓ Its SI unit is **Tesla** (T)

$$1T = \frac{1N}{C.m/s} = \frac{1N}{A.m}$$

- ➢ A non-SI unit of $\vec{B}$, in common use, called the gauss (G)

$$1T = 10^4 \text{ G.}$$

Example

Find the current in a long straight wire that would produce a magnetic field twice the strength of the Earth’s magnetic field (The Earth’s magnetic field is about 5×10^{-5}T)at a distance of 5.0 cm from the wire.

Magnetic force

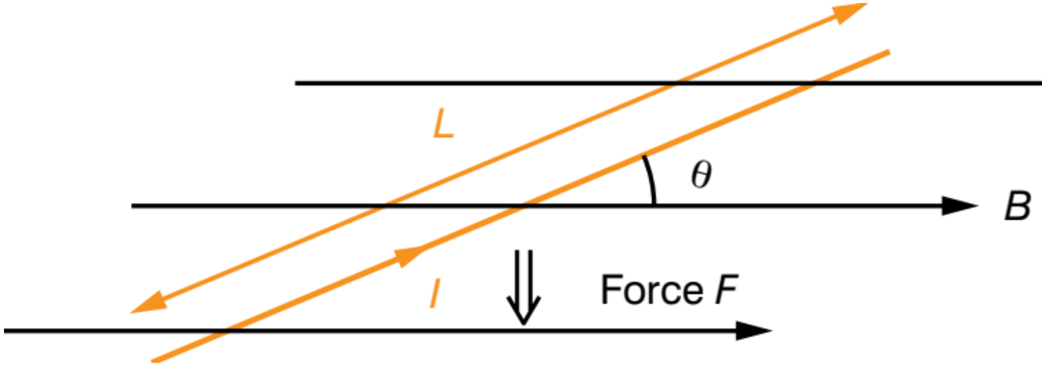
A current-carrying wire in a magnetic field will experiences a force. Factors affecting this force are;

1. Current (I): Higher current → greater force.
2. Length (L): Longer wire → greater force.
3. Magnetic Field Strength (B): Stronger field → greater force.

Formula:

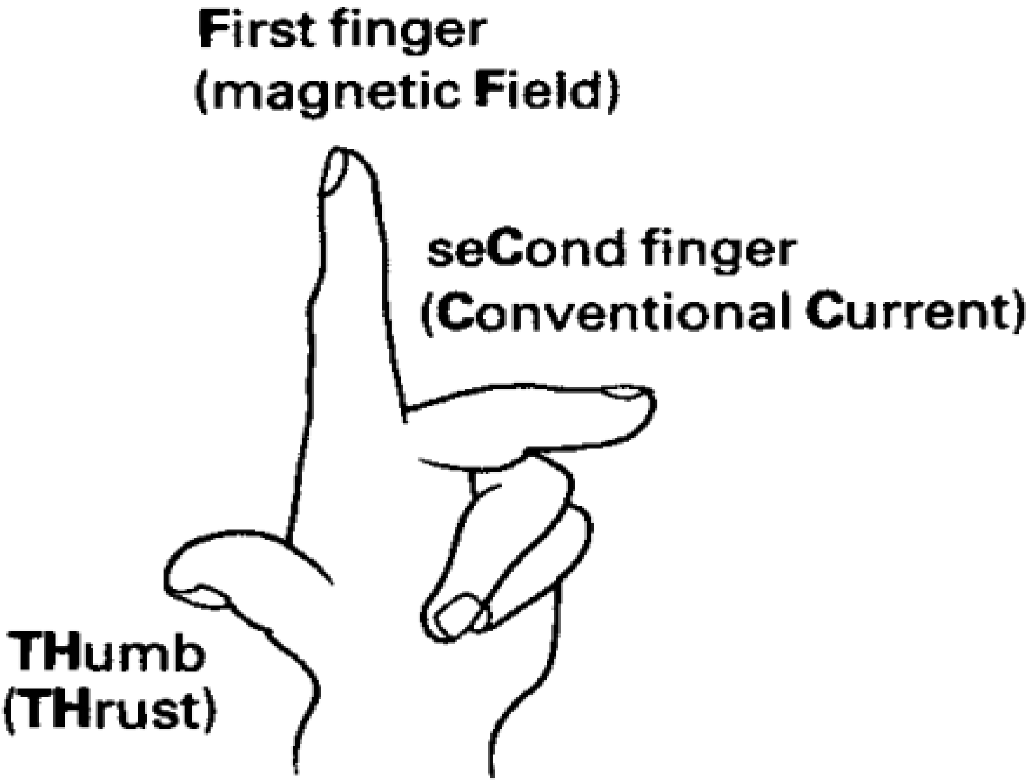
Full force: $F= BIL$ (current perpendicular to field).

General case : $F = BIL\sin\theta$ (angle θ between current and field).



Fleming's Left-Hand Rule

- Thumb: direction of motion (thrust).
- First Finger: direction of the magnetic field.
- Second Finger: direction of the conventional current.



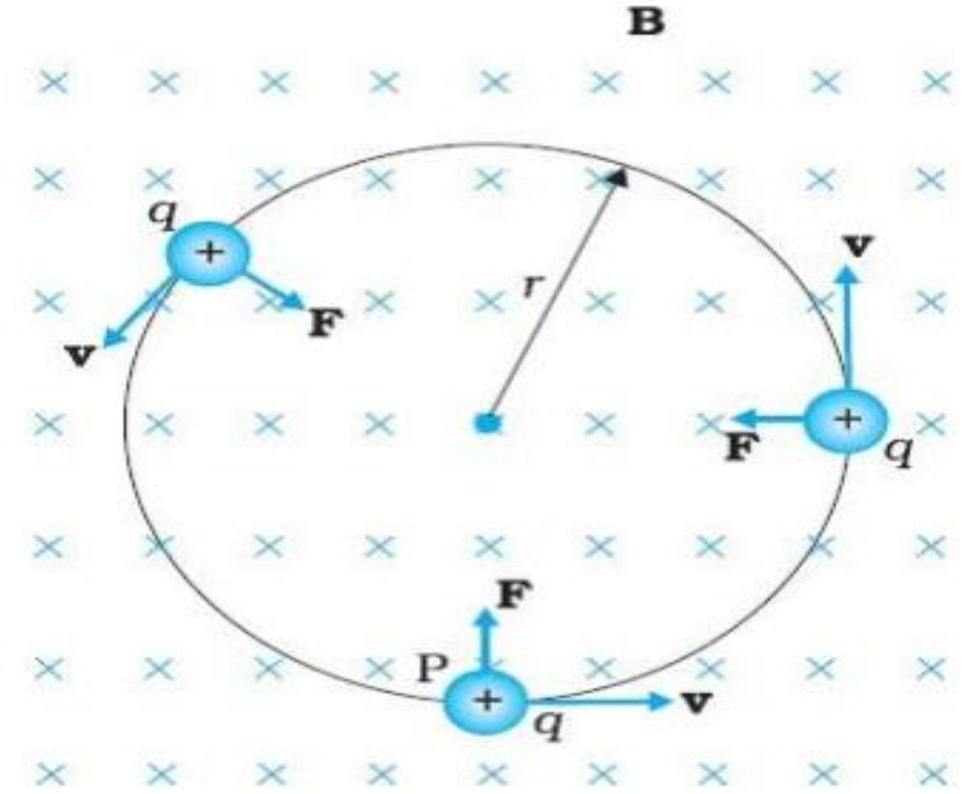
Fleming's Left Hand Rule .mp4

There are occasions when individual charges travel through a magnetic field. Even a single charge moving along constitutes an electric current.

- The ‘IL’ part of the F = BIL expression for the magnitude of the force is replaced jointly by two factors: the size of the charge, q, and its velocity, v. Therefore, for a single charge, the force is given by: $F = Bqv$
- A charged particle moving in a magnetic field will move in a circular path. In this situation, a charged particle is subjected to the centripetal force equal to the magnetic force experienced by a charge;

$$\frac{mv^2}{r} = Bqv$$

$$B = \frac{mv}{qr}$$



Example

A particle of mass 1.7×10^{-27} kg and velocity 8.0×10^{6} m/s has a charge of 1 c and moves in a radius of 200 m. What is the magnetic field strength?

An electron moving with a speed of 2.2 x 10^{7} m/s east enters in the region of magnetic field strength of 5 x 10^{-4} T directed north. What is the magnetic force experienced by the electron? **(UEE 2015)**

A. 1.76 x 10^{-15} N towards north direction

B. 3.64 x 10^{-30} N to wards east direction

C. 8.00 x 10^{-15} N perpendicular to north and east directions.

D. 1.76 x 10^{-15} N perpendicular to north and east directions.

Magnetic Force Between Parallel Wires

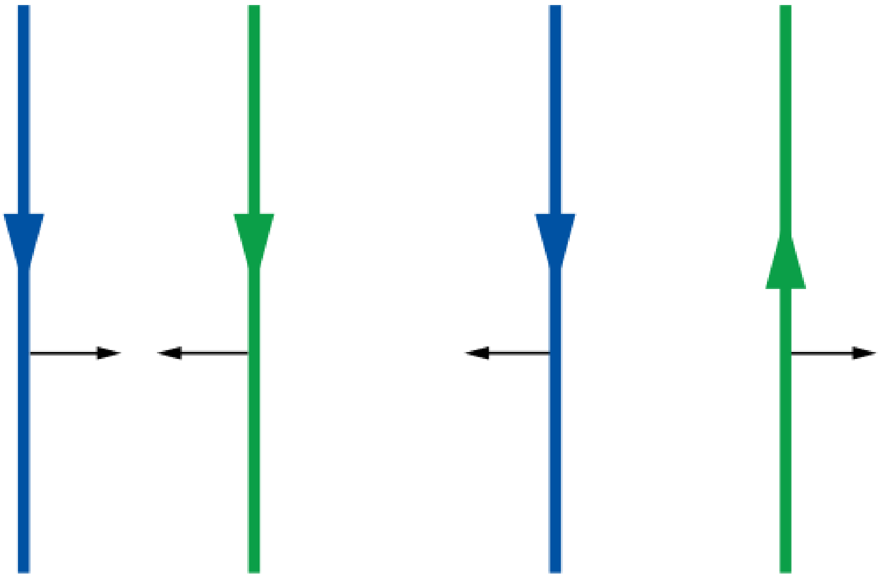
Attraction: Currents in the same direction attract

Repulsion: Currents in opposite directions repel

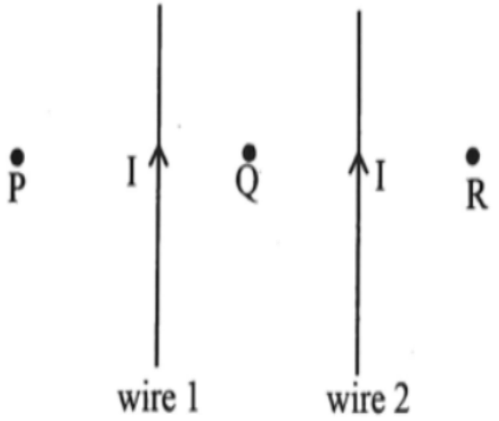
Standard Ampere Definition:

- **1 ampere:** Two wires 1 m apart in vacuum experience 2×10^{-7} N/m force.

Magnetic Force between Two current carrying Conductors.mp4



Consider two parallel long straight conductors carrying equal current I along the positive y direction as shown in below. **(UEE 2016(T))**



Force on a current carrying conductor.mp4

The net magnetic field due to the two current carrying conductor is**(UEE 2016(T))**

A. Zero at a point midway between the conductors.

B. In the direction of the currents in the region between the two wires (at point Q)

C. Directed out of the page of the paper at point R.

D. Directed in to the page of the paper at point P.

A current of 5A flows through the circuit when the switch in the figure blow is closed. What would be the copper wire suspended on the clamp? (UEE 2011)

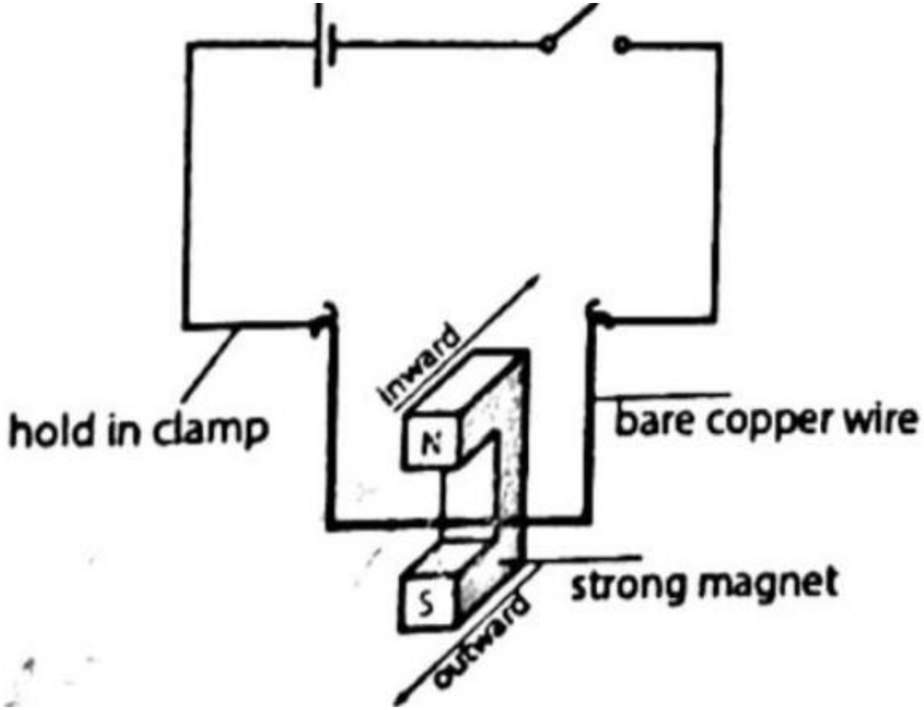
A. be deflected in ward

B. be deflected outward

C. be lifted upward

D. experience no force

Force on a current carrying conductor.mp4

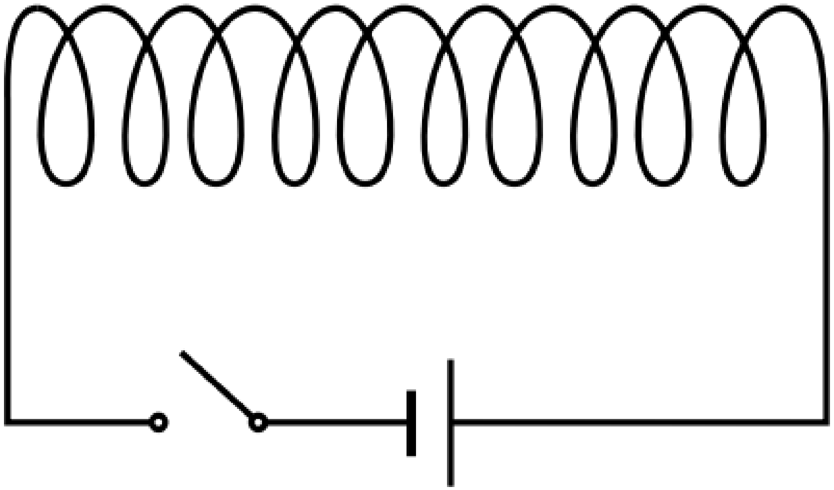


Magnetic field of a solenoid

Brainstorming Questions

1. What happens to the magnetic field inside and outside a solenoid when current flows through it?
2. How does the number of turns of wire per meter affect the magnetic field strength?
3. Why is the field strong & uniform inside the solenoid and weaker outside?

- **Solenoid:** ***a number of turns coils of wire in which a magnetic field is created by passing a current through it***



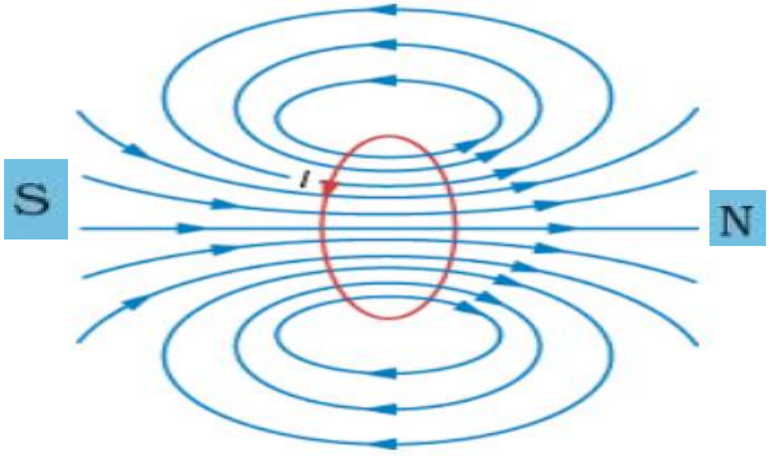
selonoid.mp4

- The currents in each side of the coil both contribute to the overall magnetic field.
  - ✓ ***The field is strong in the center of the coil but weaker outside the coil, b/c inside the coil, field lines add up; outside, they spread out and weaken.***

In a solenoid, the magnetic field is made up from that produced by each turn.

- ✓ Inside the solenoid the field is strong and uniform, while outside it the field resembles that of a bar magnet as shown in below.
- ✓ right-hand rule to work out which end of a solenoid is the north pole and which is the south.

The thumb points to the north pole, if the fingers point in the direction of the current.



Solenoid Animations.mp4

Strength of magnetic field in a solenoid

The strength of the magnetic field in a solenoid (again given the symbol B) depends on:

- the number of turns of wire per meter of length, **n**.
- the permeability of free space, $\boldsymbol{\mu_o}$.
- the current flowing through the wire, **I**

solenoid.mp4

$$\mathbf{B} = \boldsymbol{\mu_o}\mathbf{nI} \quad \text{where } \boldsymbol{n} = \frac{\boldsymbol{N}}{\boldsymbol{l}}$$

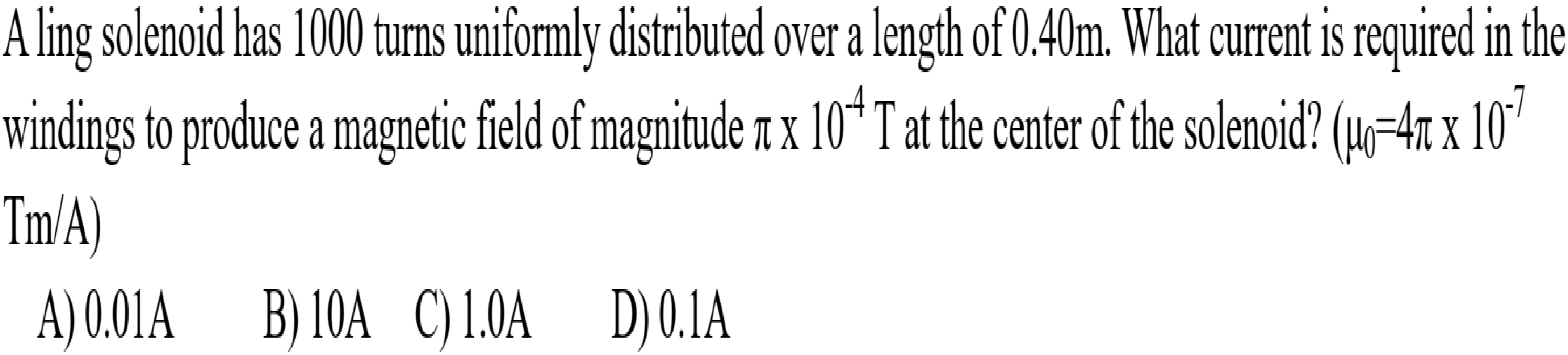
Activity!

1. Why is a solenoid behave like a bar magnet when current passes through it?
2. If the current in a solenoid is doubled, how is the magnetic field affected?

Example

Find the magnetic field strength at the center of a solenoid with 5 m of length and 5000 turns, when a current of 5 A passing through it

EGSSLCE (2005)



A ling solenoid has 1000 turns uniformly distributed over a length of 0.40m. What current is required in the windings to produce a magnetic field of magnitude $\pi \times 10^{-4}$ T at the center of the solenoid? ($\mu_0=4\pi \times 10^{-7}$ Tm/A)

A) 0.01A B) 10A C) 1.0A D) 0.1A

The Motor Effect

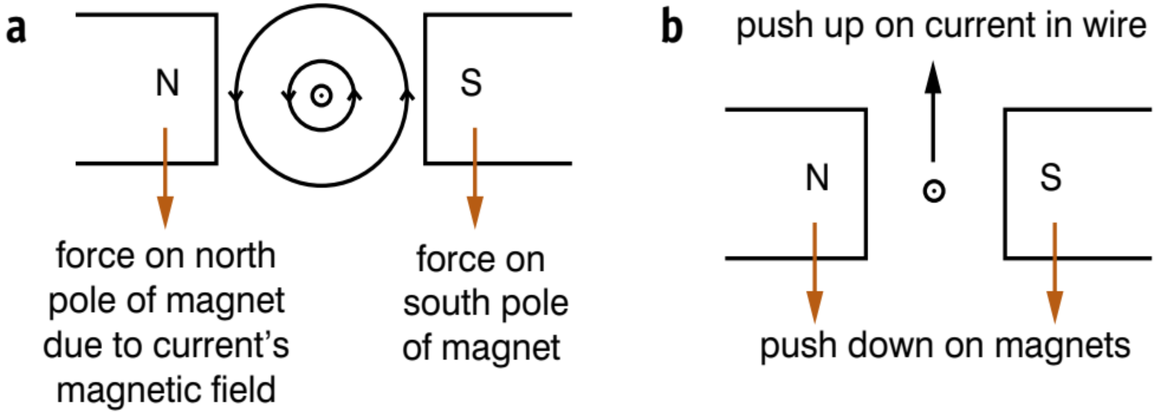
Brainstorming Questions

1. What causes the force on a current-carrying wire in magnetic field?
2. How does the orientation of the wire relative to the magnetic field affect the force?

Definition: When a current-carrying conductor is placed in a magnetic field, it experiences a force due to the interaction of the fields.

Explanation:

- Magnetic lines of force show the force on a north pole; south poles feel opposite forces.
- When current flows, magnets experience force downward, and the wire feels an upward force (Newton's Third Law).



Force on a Rectangular Coil

Torque: Two forces on opposite sides of the coil create a turning effect.

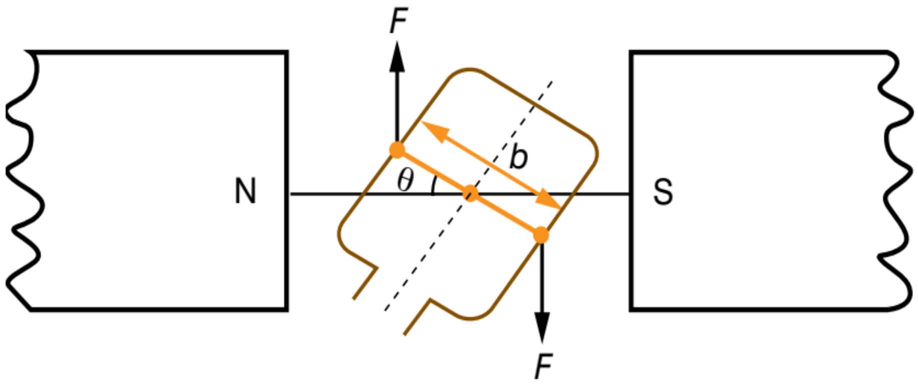
- ✓ Force on each side: $F = BILN$ (N = number of turns).
- ✓ Torque: $\tau = BINLb\cos\theta$

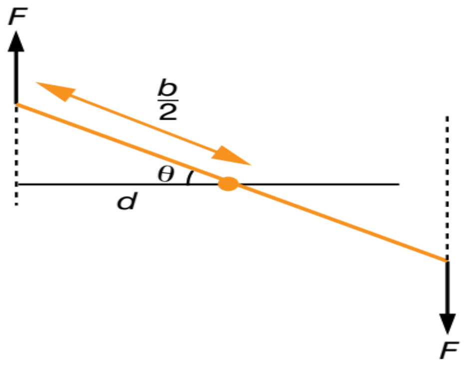
  $\tau = BINA\cos\theta$ (A = area of coil).

Maximum Torque: When $\theta = 0^0$.

Zero Torque: When $\theta = 90^0$.

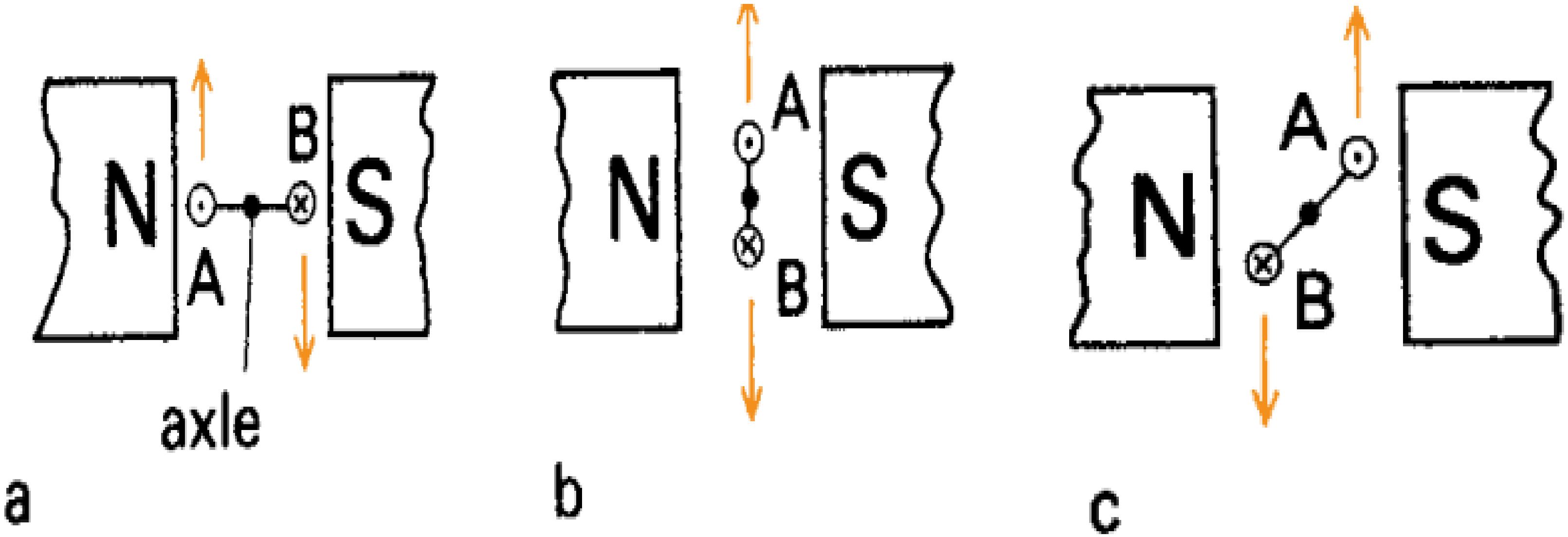
- ✓ These principles explain electric motors and magnetic interactions in current-carrying conductors.





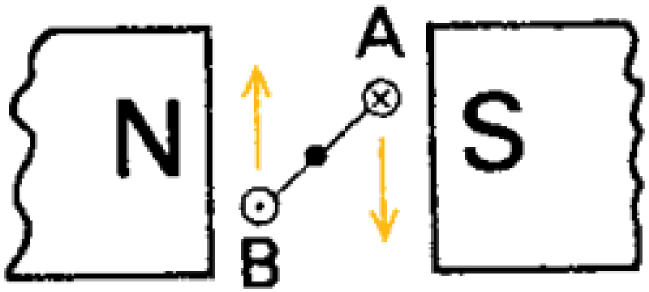
The working principles of electric motor

1. Principle:
   - ✓ A coil carrying current in a magnetic field experiences forces predicted by Fleming's Left-Hand Rule, causing it to rotate.
2. Coil Behavior:
   - ✓ Starts rotating due to forces (Fig. a).
   - ✓ Stops after a quarter-turn (Fig. b) unless the current direction is reversed.
   - ✓ If you pushed the coil round a bit more, the forces on the coil would simply return it to the upright position (Fig. c)



3. Continuous Rotation:

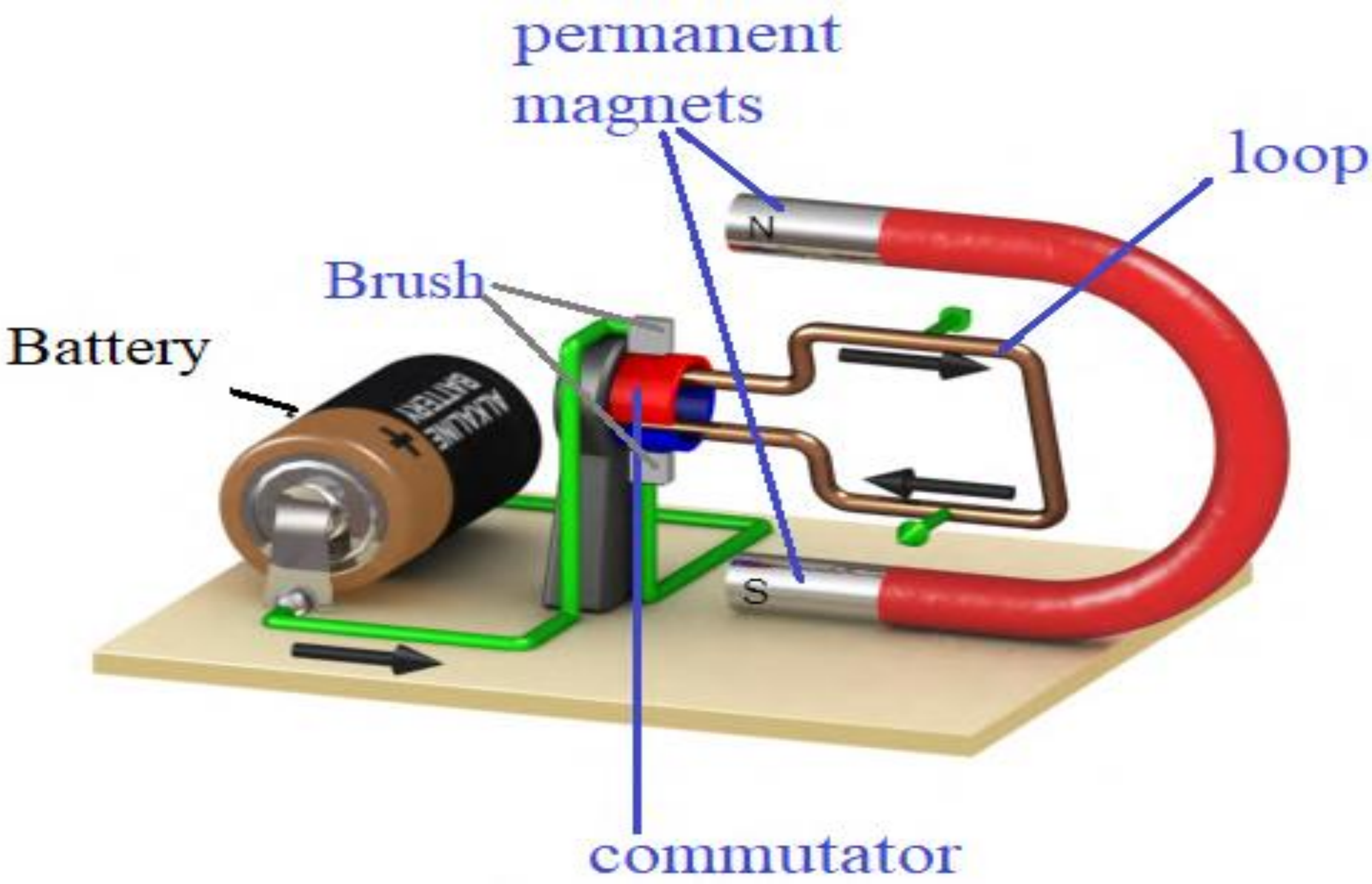
- ✓ Split-Ring Commutator: Automatically reverses the current at the right moment, enabling continuous rotation (Fig. below).



4. Brushes:

- ✓ Conduct current to the coil via the commutator.
- ✓ Material: Usually carbon (resists corrosion and sparking).
- ✓ Maintenance: Brushes wear out and need periodic replacement.

Unit 4 Electromagnetism



Electric Motor .mp4

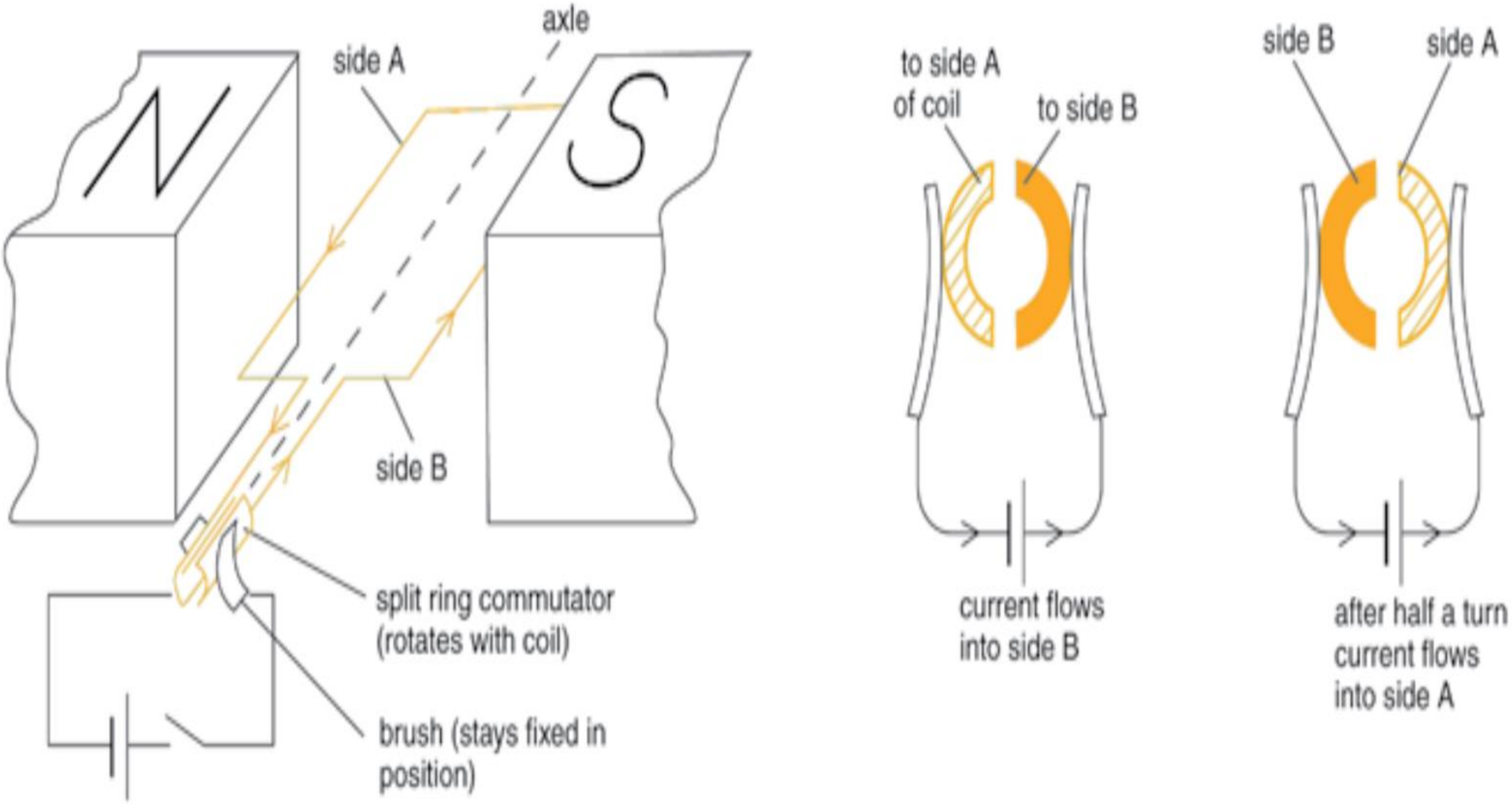


Fig. How the direction of the current is reversed every half-turn of the coil.

Key Components

- Coil: Rotates in the magnetic field.
- Magnetic Field: Provides the turning force.
- Commutator: Reverses current to sustain motion.
- Brushes: Connect the power source to the coil.

Activity!

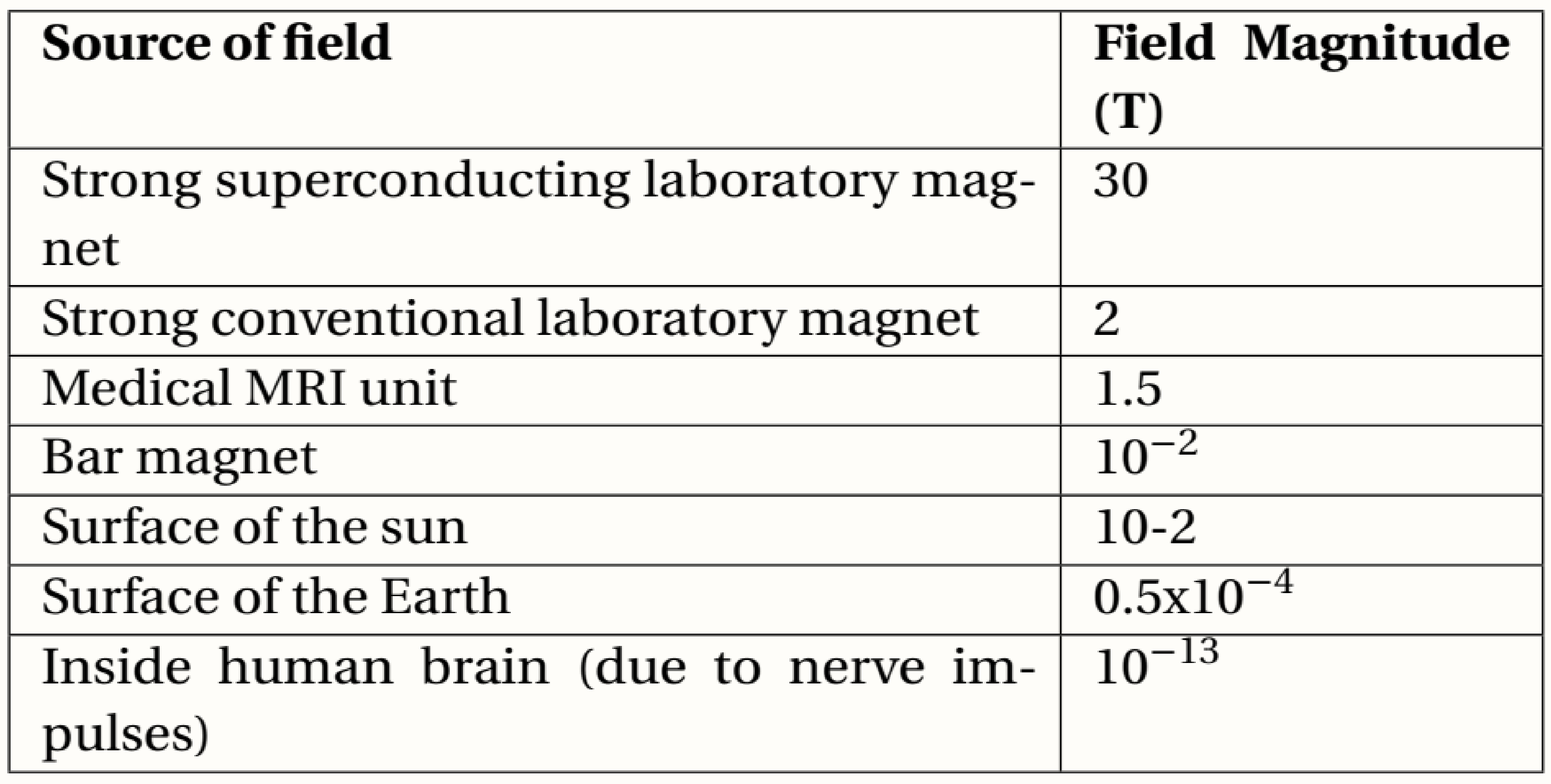
1. Why does a magnetic a rectangular coil experience a turning effect when placed in magnetic field?
2. Why does the torque on a current-carrying coil become zero when the coil is perpendicular to the magnetic field?

Applications Ampere’s Circuital Law

Brainstorming Questions

1. How does Ampere’s circuital law connect electrical current and the resulting magnetic field in a closed loop?
2. Why is ampere’s circuital law important in understanding the design of electromagnetic devices?
3. What factors affect the magnetic field strength in a current-carrying coil?

- ✓ Magnetic field around a current is proportional to the current.
- ✓ Applied in motors, generators, transformers, cylindrical conductor, solenoids, and toroid.

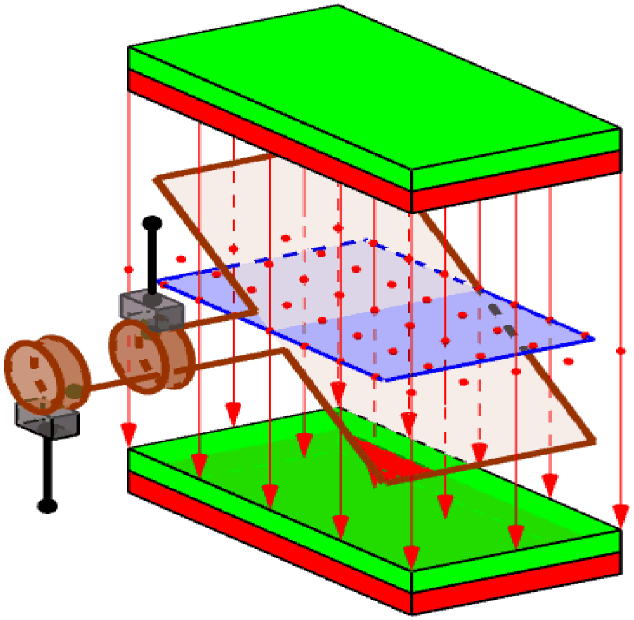


Source of field	**Field Magnitude (T)**
Strong superconducting laboratory magnet	30
Strong conventional laboratory magnet	2
Medical MRI unit	1.5
Bar magnet	10^{-2}
Surface of the sun	10-2
Surface of the Earth	$0.5\text{x}10^{-4}$
Inside human brain (due to nerve impulses)	10^{-13}

Electromagnets:

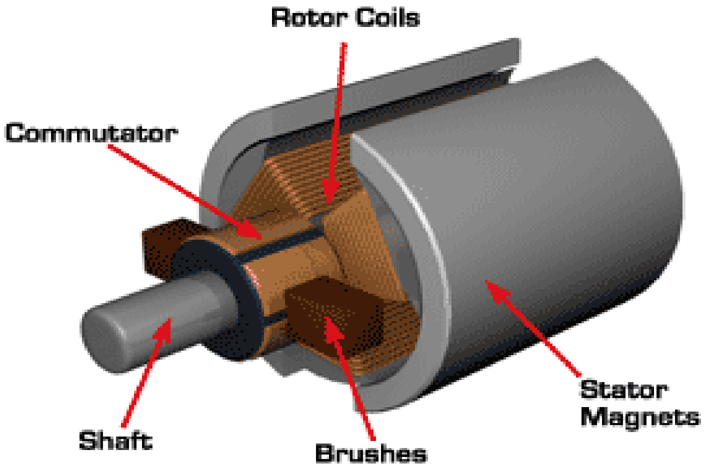
- ✓ Magnetic field created by current through a coil around a magnetic material.
- ✓ Temporary magnets.
- ✓ used in generators, motors, MRI machines, electric fans, magnetic relays, electric bells etc.

a. Generator

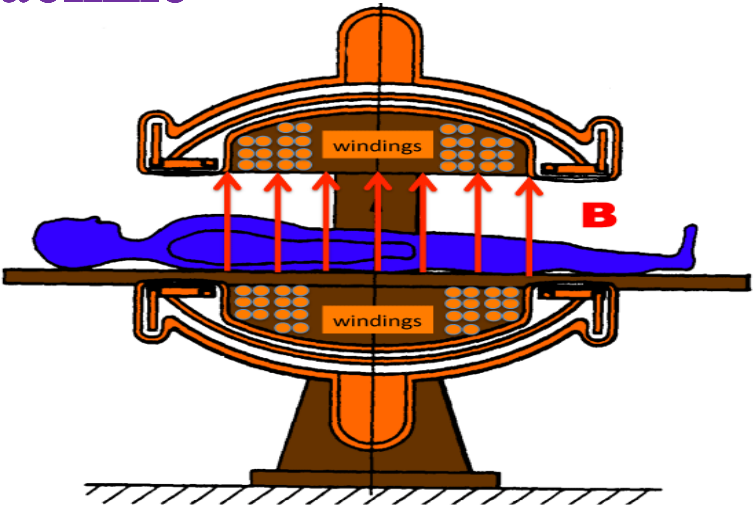


AC_Generator.mp4

b. Motors



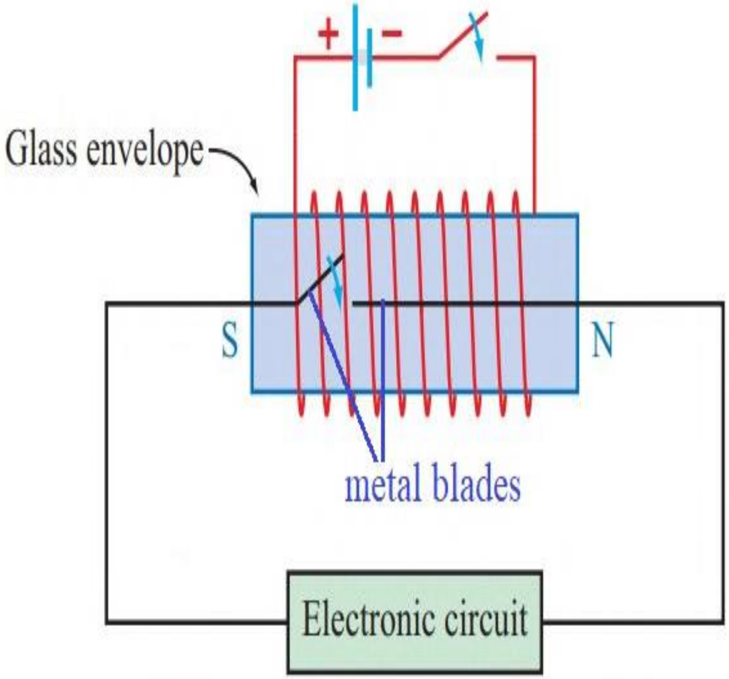
c. MRI machine

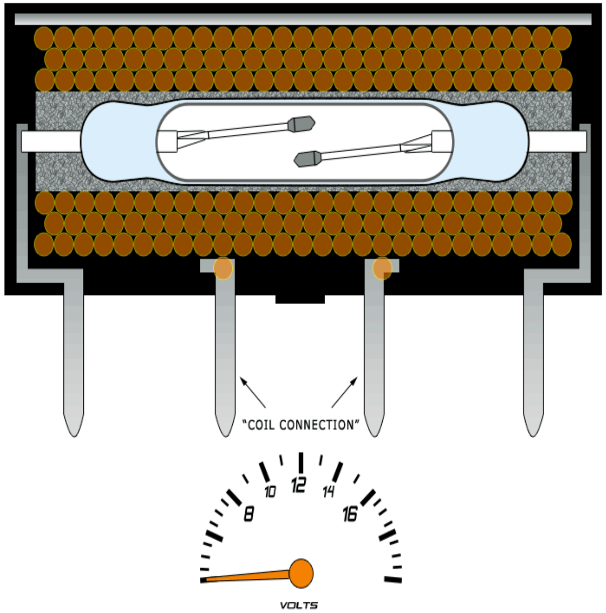


d. Electric Fan

e. Magnetic Relays:

- ✓ Electrically operated switches using magnetic forces (e.g., reed relay in telephone systems).

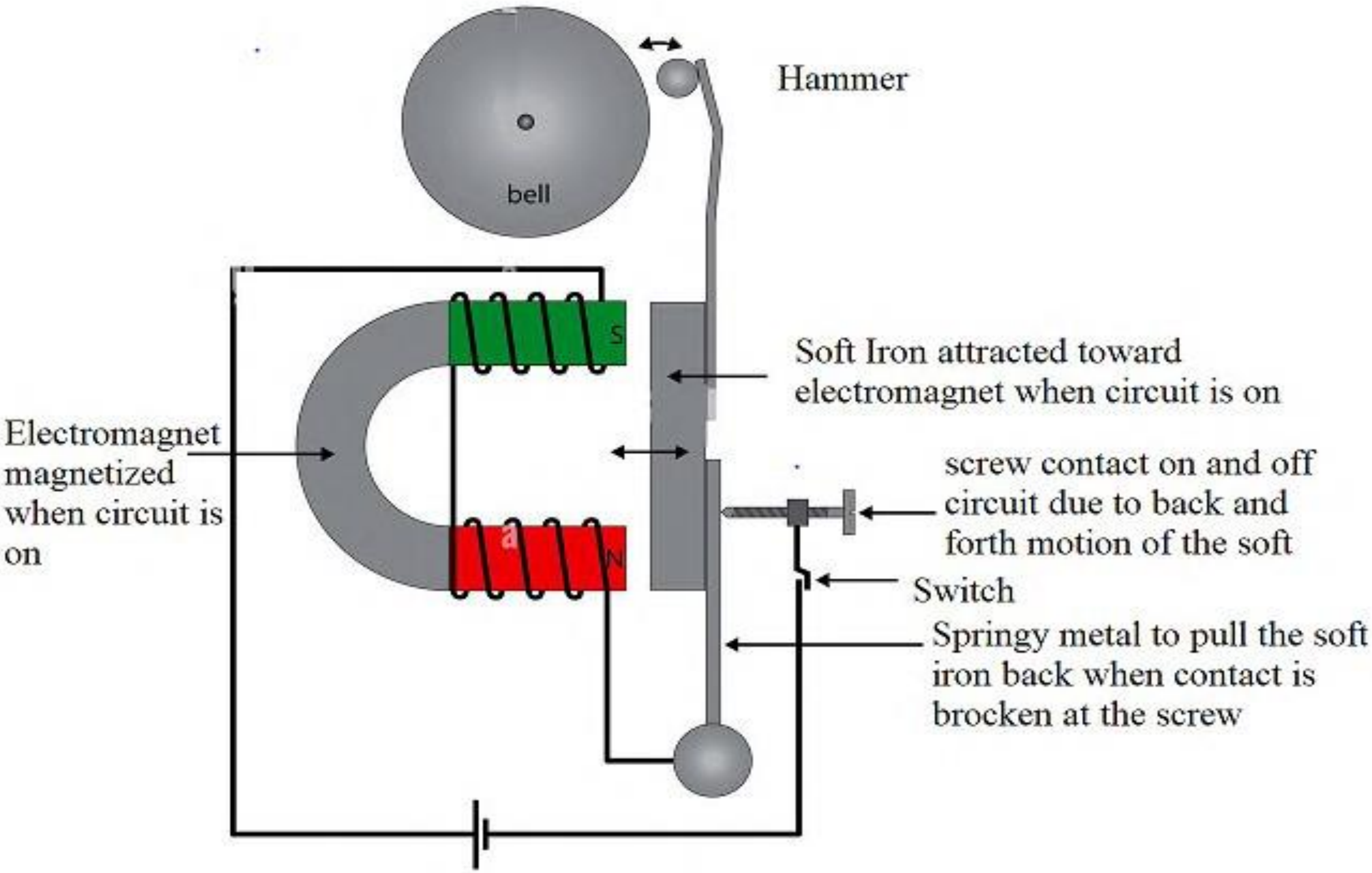




f. Electric Bell:

- ✓ Uses electromagnetism to produce sound by repeatedly striking a bell when current flows.

Electric Bell.mp4



Activity!

List some devices that use Ampere’s circuital law to be functioned?

4.4 Electromagnetic Induction

Brainstorming Questions

1. Can electricity be generated with ought a power source? If yes:
    a) how might this be achieved?
    b) what are some examples in daily life where this method might be used?
    c) is this method is important? If yes, why?
2. What do you think the term “flux” refers to in physics? How might it apply to magnetism?
3. If you imagine magnetic field lines passing through a surface, what factors might determine how many lines pass through?

Introduction

- Initially, electricity and magnetism were viewed as separate phenomena.
- Early 19th-century experiments by Oersted and Ampere revealed the relationship between electricity and magnetism.
- A moving electric charge produces a magnetic field, leading to the question: Can moving magnets produce electric currents?

Faraday’s Discovery

- Michael Faraday discovered that changing magnetic fields could generate electricity.

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generator_en (1).jar

- **Electromagnetic Induction**: A varying magnetic field induces an electromotive force (emf) that produces an electric current in a closed circuit.
- Faraday's experiments led to the invention of the dynamo (generator).

Practical Importance:

- Faraday’s and Henry’s work laid the foundation for modern generators and transformers.
- Electromagnetic induction is crucial in today’s technology, from electricity generation to various electrical devices.

Magnetic Flux (Φ)

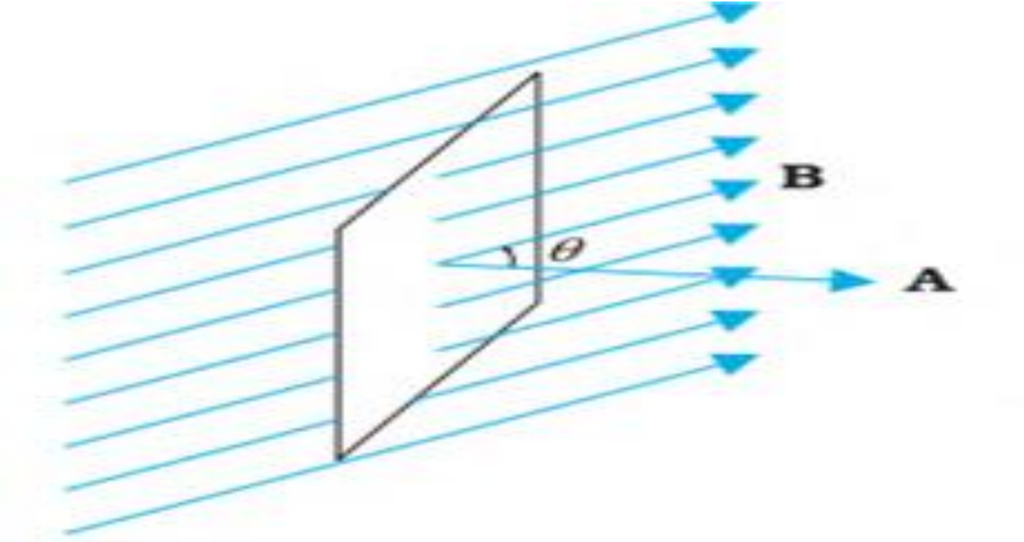
- measures the total magnetic field passing through a given area.
- For a surface area (A) in a magnetic field (B), magnetic flux is calculated by:

$$\phi_B = \mathbf{B}.\mathbf{A} = BA\cos\theta$$

Where (θ) is the angle between the magnetic field and the area.

VideoTrimmer_magnetic flux.mp4

- SI unit: $T.m^2$ = weber (W_b)



Example

1. A square loop of side 3 cm is positioned in a uniform magnetic field of magnitude 0.5 T so that the plane of the loop makes an angle of 60^0 with the magnetic field as shown in Figure above: Find the flux passing through the square loop?

2. A circular loop of area 200 cm^2 sits in the xz plane. If a uniform magnetic field of B= (0.3$\hat{\imath}$+0.4$\hat{\jmath}$)T is applied on it. Determine the magnetic flux through the circular loop?

UEE Questions

A magnetic field strength $5 \times 10^{-5} T$ passes through an area of 20 cm^2 that is at an angle of 60^0 to the magnetic field. What is the magnetic flux? (UEE 2010)

A. $0\ Wb$

B. $5 \times 10^{-8}\ Wb$

C. $2.5 \times 10^{-8}\ Wb$

D. $8.7 \times 10^{-8}\ Wb$

4.5 Faraday’s Law of Electromagnetic Induction

Brainstorming Questions:

1. If a magnet is dropped with its north pole toward a coil connected to an ammeter, in which direction (clockwise or counterclockwise) will the current flow?
2. How does the speed of relative motion of between a magnet & a coil affect the induced emf?

Key Conclusions from Faraday’s Experiments:

1. Induced Current is produced when there is relative motion between a coil and a magnet.
2. The direction of the induced current depends on:
   - ✓ the pole of the magnet.
   - ✓ the direction of motion of the magnet or coil.

michael faraday.mp4

Faraday’s Law of Electromagnetic Induction:

- ✓ states that “the magnitude of the induced electromotive force (emf) is directly proportional to the rate of change of magnetic flux in a closed coil”.

$$\varepsilon = -\frac{\Delta\phi_B}{\Delta t}$$

Where, ε: Induced emf (voltage)

$\Delta\phi_B$: change in magnetic flux

Δt : change in time

- ✓ Negative sign: Indicates the direction of emf and current (Lenz’s Law).

For a coil with N turns:

$$\varepsilon = -\frac{N\Delta\phi_B}{\Delta t}$$

- ✓ The induced emf increases with the number of turns (N).

Factors Affecting Induced emf:

1. The rate of change of flux increases the induced emf.
2. Induced emf increases when:
   - ✓ A stronger magnet is used.
   - ✓ The speed of relative motion between the coil and magnet increases.
   - ✓ The number of turns in the coil increases.

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Example

A square loop of side 10 cm and resistance 0.5 Ω is placed vertically in the east-west plane. A uniform magnetic field of 0.10 T is set up across the plane in the northeast direction. The magnetic field is decreased to zero in 0.70 s at a steady rate. Determine the magnitudes of induced emf and current during this time-interval.

UEE Questions

1. A rectangular loop area $0.4m^2$ is placed in a magnetic field that is changing at a rate of 100T/s. If the normal of the loop makes angle 60^0 with the magnetic field, what is the magnitude of the induced emf?(UEE 2011)

A.80 V B. 40 V C. 20 V D. 34.64 V

2. A magnetic field intensity of 4 x 10^{-4} T crosses a coil having face area 100 cm^2 and 5 x 10^4 turns perpendicular to the face of the coil. If the magnetic flux in the coil set to zero with in 2 ms. What is the magnitude of induced emf in the coil? **(UEE 2015)**

A.$2x10^{-5}$ V B. 10 V C. 100 V D. 4 x 10^{-4} V

Lenz's Law of Electromagnetic Induction:

Brainstorming Questions

1. What is Lenz's law, and how does it relate to Faraday's law of electromagnetic induction?
2. What is the effect of reversing the pole of a magnet moving through the coil on the induced current?
3. What happens to the induced current if the coil is in motion instead of a magnet?

✓ states that “the induced current always flows in a direction that opposes the change that causes it”.

➢ The induced current creates a magnetic field that opposes the change in magnetic flux, ensuring that the original flux is maintained.

➢ Mathematical Representation (related to Faraday’s Law):

$$\varepsilon = -\frac{N\Delta\phi_B}{\Delta t}$$

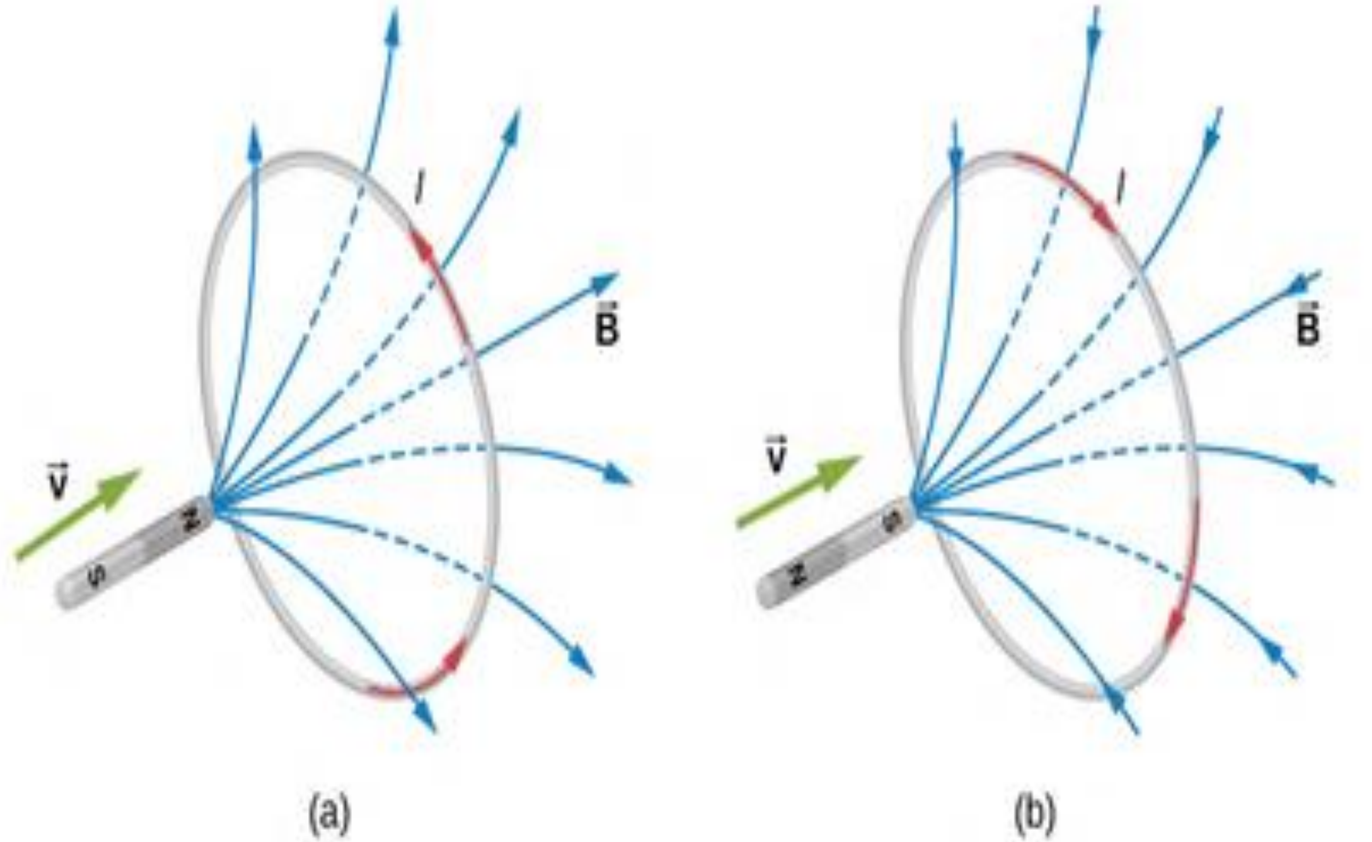
✓ The negative sign indicates the opposing nature of the induced current (Lenz’s Law).

Key Points:

Lenz's Law.mp4

❖ Lenz’s Law is based on conservation of energy and Newton’s third law.

- It provides a simple way to determine the direction of the induced current.



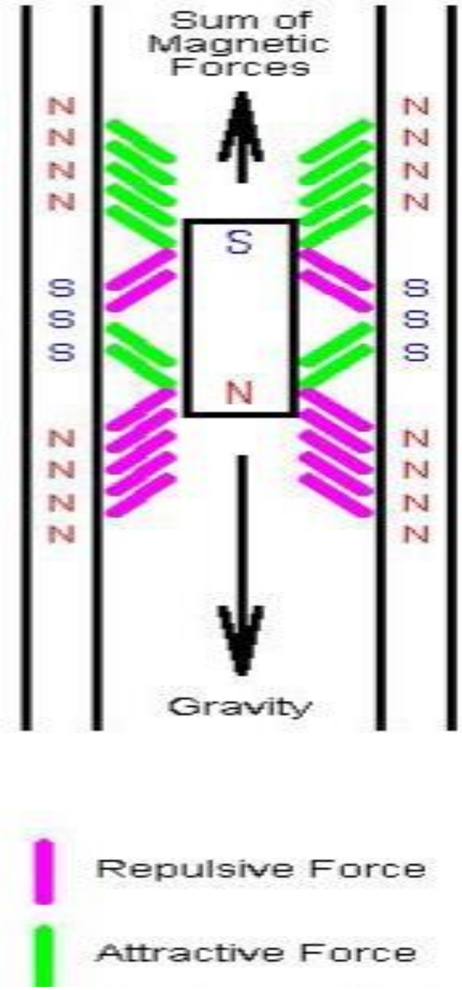
Activity!

1. Explain how Lenz's law supports the principle of conservation of energy?
2. When a magnet is dropped through a copper tube, it falls slower than expected. How does Lenz's law explain the opposing force that slows the magnets motion?

Real-world scenarios where Lenz’s law is applicable

1. Dropping a magnet through a copper pipe

✓ the magnet falls slower than expected



2. Induction mobile chargers (wireless chargers)

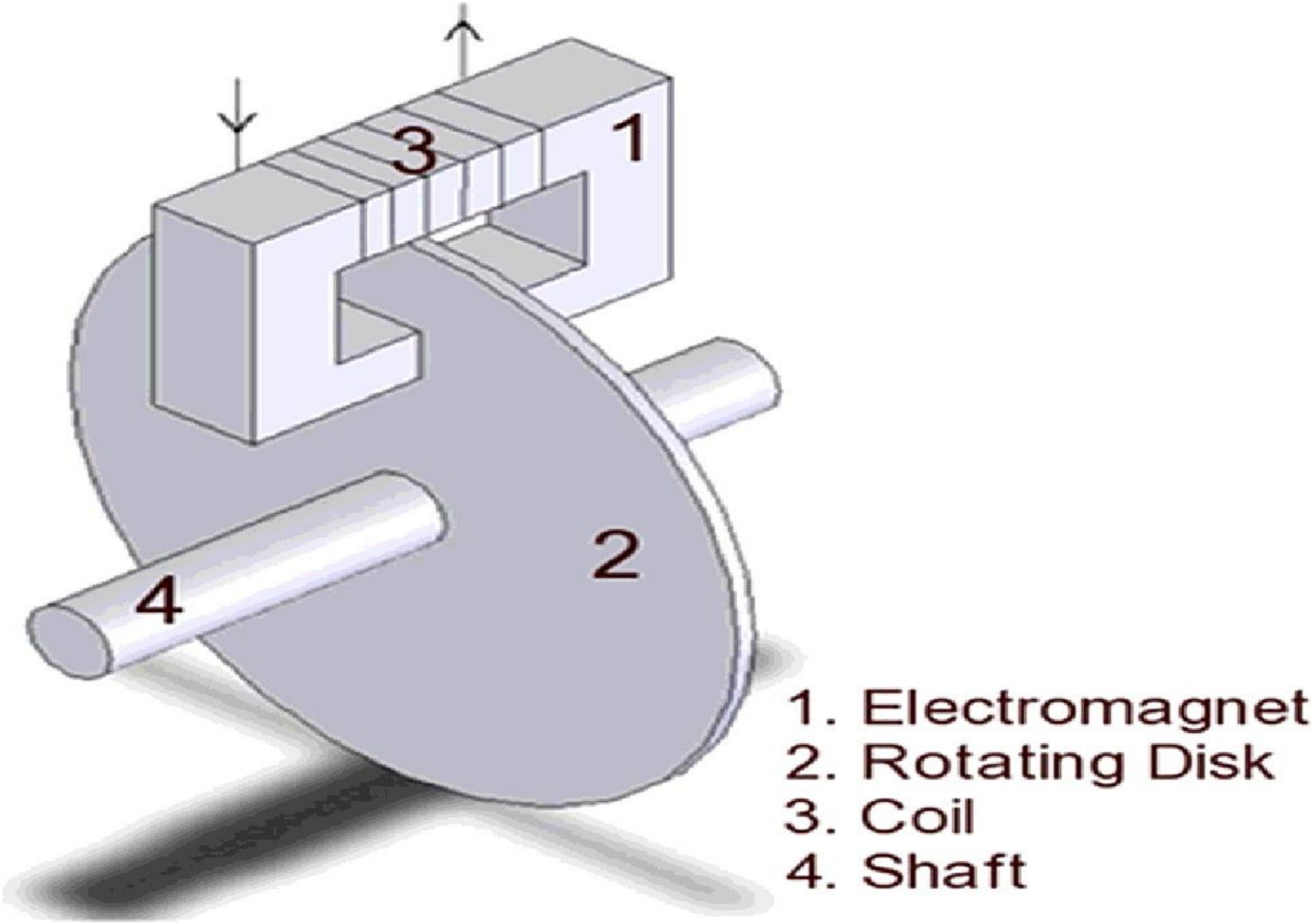
- ✓ A charging pad coils uses AC to generates magnetic field which induces a current in the coil inside the devices & the device convert it into DC to charge its battery

3. Induction stove

- ✓ It heat up quickly a metal pot (generate heat)

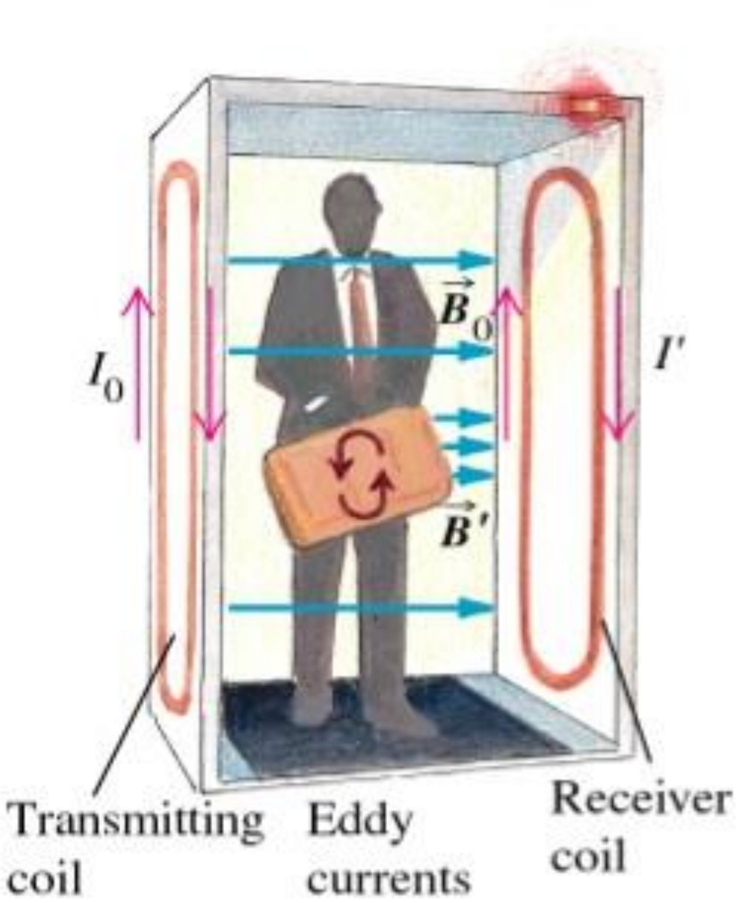
4. Electric breaking in trains

- ✓ A magnetic field is applied to the rotating wheel to slowdown it.



5. Metal detectors

✓ A changing magnetic field of metal detector produce the magnetic field in the metal w/c is detected by metal detector.


$\vec{B}_0$
I_0
I'
$\vec{B}'$
Transmitting coil
Eddy currents
Receiver coil


SUPER SCANNE

Inductor

- ✓ A device that resists changes in current by inducing an electromotive force (e.m.f.).
- ✓ It consists of a coil, often with an iron core, which enhances its effect.

Air-cored Inductor: no magnetic material in the core.

Iron-cored Inductor: contains an iron core to enhance magnetic effects.

Inductance:

- ✓ is the property of a circuit to induce an e.m.f. opposing a change in current.

*A larger inductance means a greater opposition to current change.

i) Self-Inductance:

Brainstorming Questions

1. What is self-induction, and how does it arise in a circuit?
2. Why is the e.m.f induced by a changing magnetic flux referred to as a “back e.m.f”?
3. Why self-induction important for the safe operation of electrical circuit?

Self-Inductance:

- ✓ When the change in current in a coil induces an e.m.f. in the same coil.
- ✓ Back e.m.f. opposes the battery voltage, delaying the current build-up.

Self Inductance.mp4 Self induction.mp4

- ✓ On switching off: high forward e.m.f. may cause sparks.

Factors affecting self inductance:

- **Number of turns (N):** more turns in a coil increase inductance
- **Core material:** magnetic materials like iron enhance inductance compared to air cores.
- **Cross-sectional area**: larger area increased inductance.
- **Length of coil:** shorter coils have higher inductance.

- A self-induced emf is always proportional to the time rate of change of the current.

$$\varepsilon = -L\frac{\Delta I}{\Delta t}$$

From Faradays law, we have;

Self Induction .mp4

$$\varepsilon = -N\frac{\Delta \phi_B}{\Delta t}$$

Combining the two equations;

$$L = N\frac{\Delta \phi_B}{\Delta I}$$

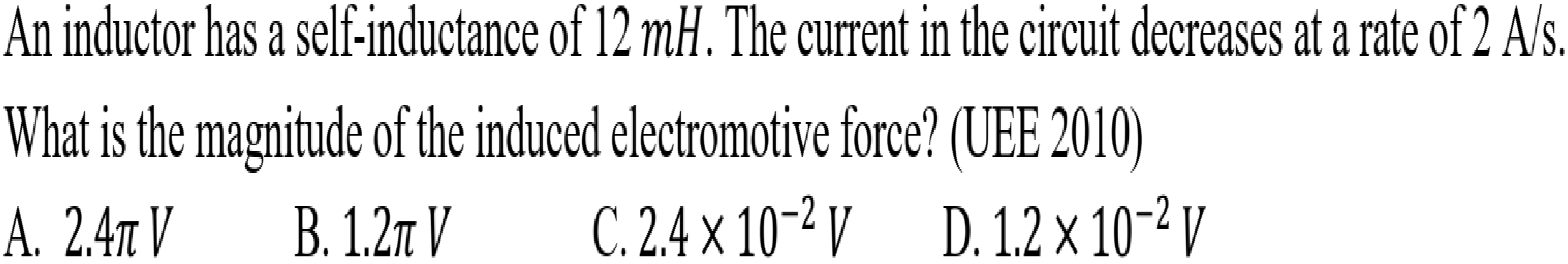
But change in magnetic flux is;

$$\Delta \phi_B = \Delta B A = \frac{\mu_o N(\Delta I)}{L} A$$

$$L = N\frac{\mu_o N(\Delta I)}{L} A = \frac{\mu_o N^2}{L} A$$

Unit of L: Henry (H). $1\text{H} = 1\text{Vs/A}$

Example

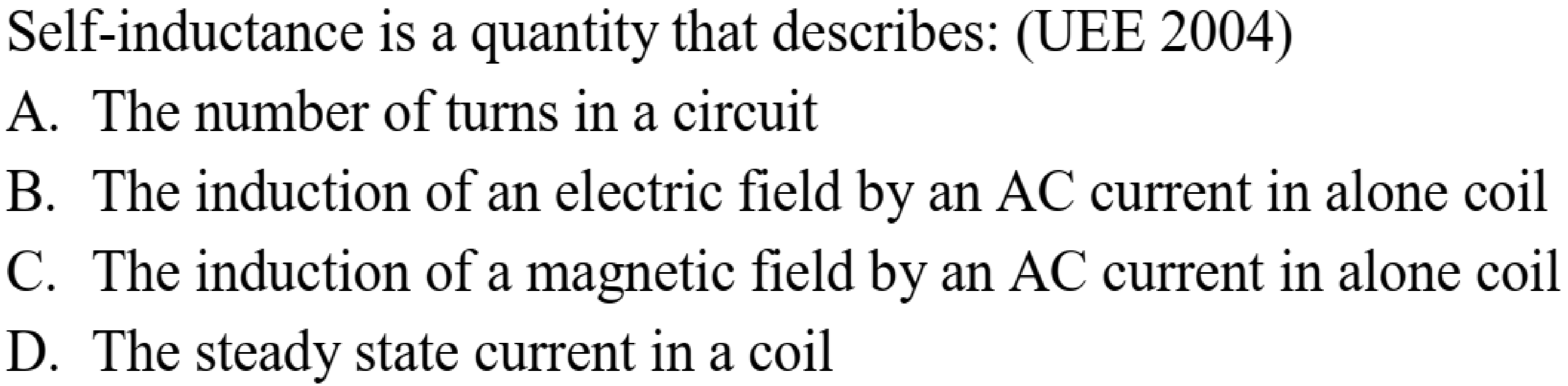


An inductor has a self-inductance of 12 mH. The current in the circuit decreases at a rate of 2 A/s. What is the magnitude of the induced electromotive force? (UEE 2010)

A. $2.4\pi\ V$ B. $1.2\pi\ V$ C. $2.4 \times 10^{-2}\ V$ D. $1.2 \times 10^{-2}\ V$

Activity!

How does self-inductance in power supply filters reduce noise and fluctuations in electronic devices?



Self-inductance is a quantity that describes: (UEE 2004)

A. The number of turns in a circuit

B. The induction of an electric field by an AC current in alone coil

C. The induction of a magnetic field by an AC current in alone coil

D. The steady state current in a coil

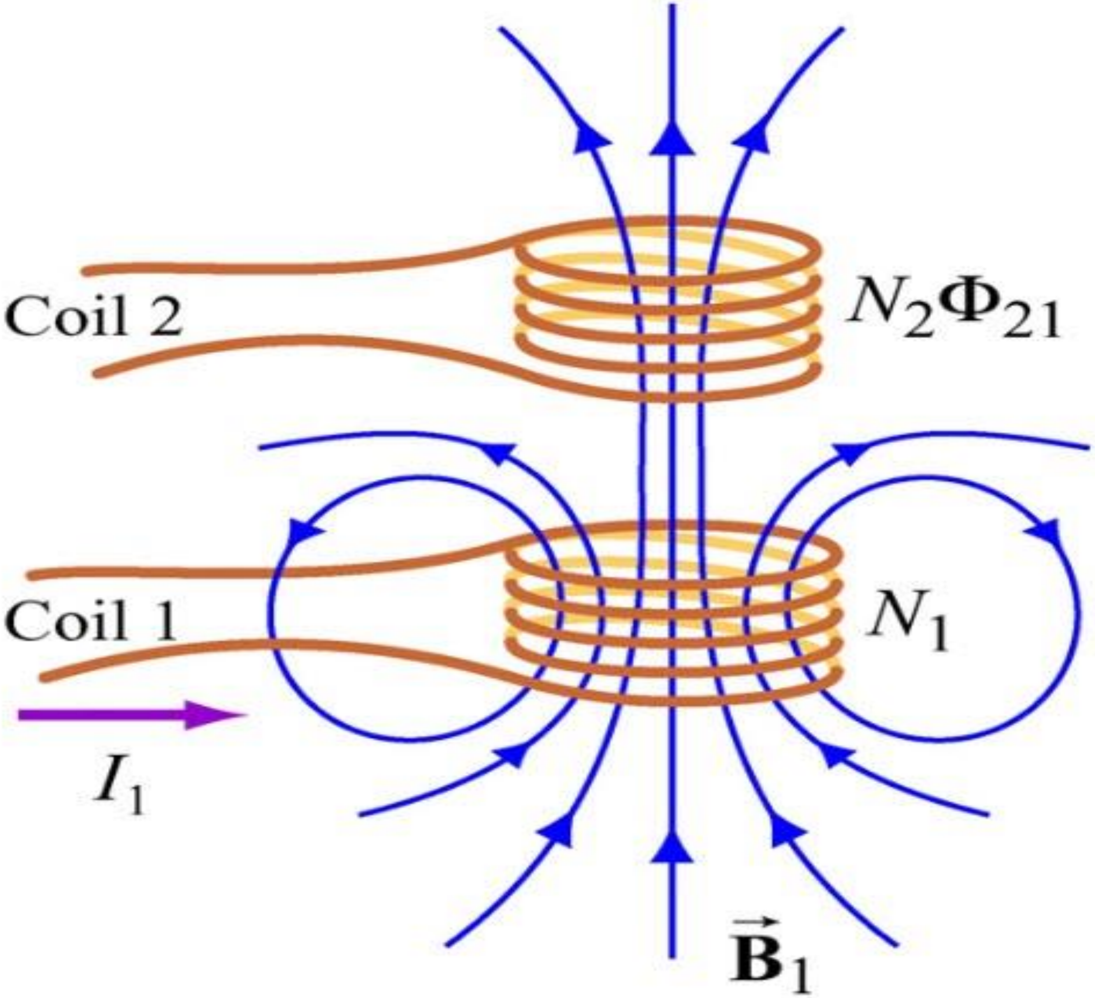
ii) Mutual Inductance:

- ✓ When a changing current in one circuit induces an e.m.f. in another circuit.

- ➢ Consider the two closely wound coils of wire shown in fig. below. The current $\mathbf{I_1}$ in coil1, which has $\mathbf{N_1}$ turns, creates a magnetic field. Some of the magnetic field lines pass through coil 2, which has $\mathbf{N_2}$ turns. The magnetic flux caused by the current in coil1 and passing through coil 2 is represented by $\boldsymbol{\phi_{21}}$. The mutual inductance M_{21} of coil 2 with respect to coil 1 is given by:

$$\mathbf{M_{21} = N_2 \frac{\Delta\phi_{21}}{I_1}}$$

- ✓ *It depends on the geometry of both circuits and on their orientation with respect to each other.*



Mutual Induction.mp4

If the current I_1 varies with time, we see from Faraday's law and Equation above, that the emf induced by coil 1 in coil 2 is:

$$\varepsilon_2 = -N_2 \frac{\Delta\phi_{21}}{\Delta t} = -N_2 \frac{\Delta}{\Delta t}\left(\frac{M_{21} I_1}{N_2}\right) = -M_{21}\left(\frac{\Delta I_1}{\Delta t}\right)$$

We can also imagine a current I_2 in coil 2. The preceding discussion can be repeated to show that there is a mutual inductance M_{12}. If the current I_2 varies with time, the emf induced by coil 2 in coil 1 is

$$\varepsilon_1 = -N_1 \frac{\Delta\phi_{12}}{\Delta t} = -N_1 \frac{\Delta}{\Delta t}\left(\frac{M_{12} I_2}{N_1}\right) = -M_{12}\left(\frac{\Delta I_2}{\Delta t}\right)$$

- ✓ *In mutual induction, the emf induced in one coil is always proportional to the rate at which the current in the other coil is changing.*

Activity!

How does mutual inductance allow for the transfer of power between the primary and secondary coils in wireless charging pad for smart phones?

Behavior of Inductors in Circuits:

1. DC Circuits:
   - ❖ For steady current:
     - ✓ ideal inductor - behaves as short circuit.
     - ✓ real inductor – behaves as resistor
   - ❖ For changing current: Inductor resists the change.
2. Time Constant ($\tau = \mathrm{L/R}$):
   - ✓ determines how quickly current builds up to (changes).
   - ✓ current rise follows an exponential curve.
   - ✓ after a time $t = \tau$, the current reaches approximately 63% of maximum value.
3. Switching Off:
   - ✓ Sudden current cessation causes a large forward e.m.f., potentially sparking.

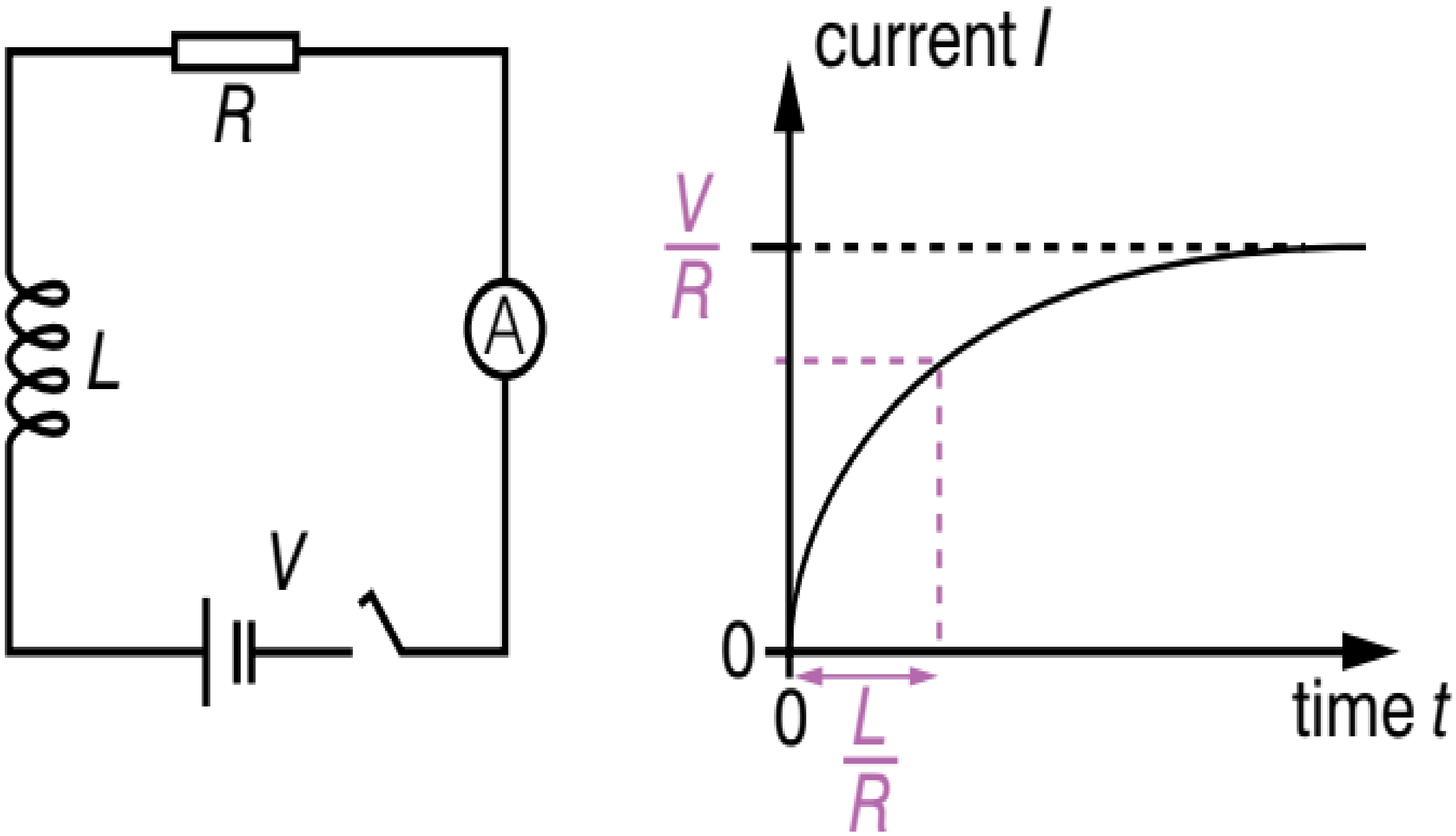


Figure: Circuit comprising a battery, an inductor and a resistor in series, and graph showing self-induced e.m.f.

Simple A.C. Generator

- ✓ an A.C generator is a device that converts mechanical energy into electrical energy by electromagnetic induction.
- ✓ It works on Faraday's Law, which states that an e.m.f. is induced when a conductor cuts through magnetic flux lines.

Key Components of an A.C. Generator:

1. Coil (Rectangular Loop):

- ✓ rotates about an axle in a magnetic field.
- ✓ induces voltage due to motion through the magnetic field.

2. Magnetic Field:

- ✓ Provides flux lines for the coil to cut through, inducing e.m.f.

3. Slip Rings:

- ✓ metallic rings connected to the coil, spinning along with it.
- ✓ allow continuous connection to the external circuit without reversing polarity.

4. Brushes:

- ✓ sliding contacts that transfer current from the slip rings to the external circuit.

Working Principle:

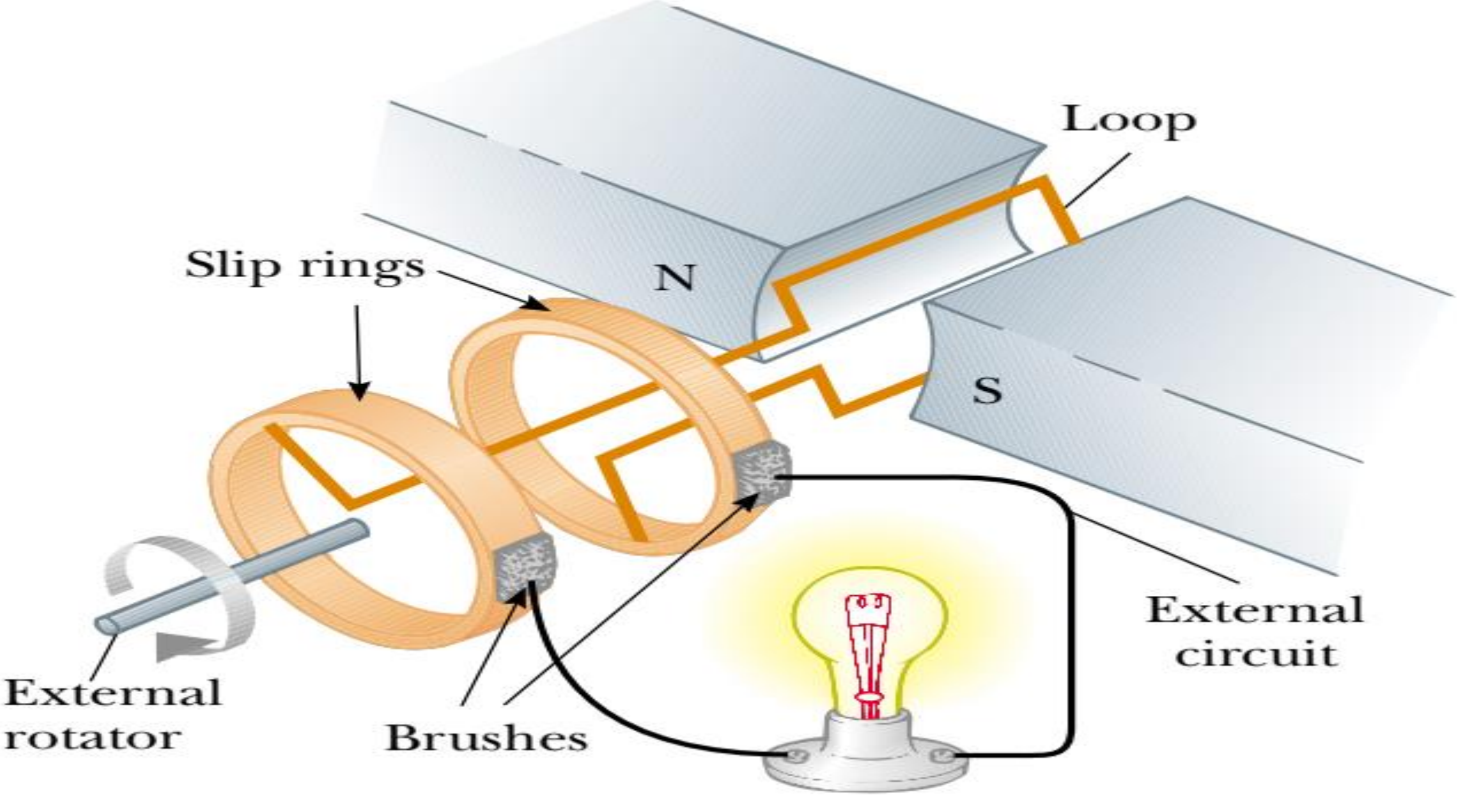
Working Principle of AC Generator!.mp4

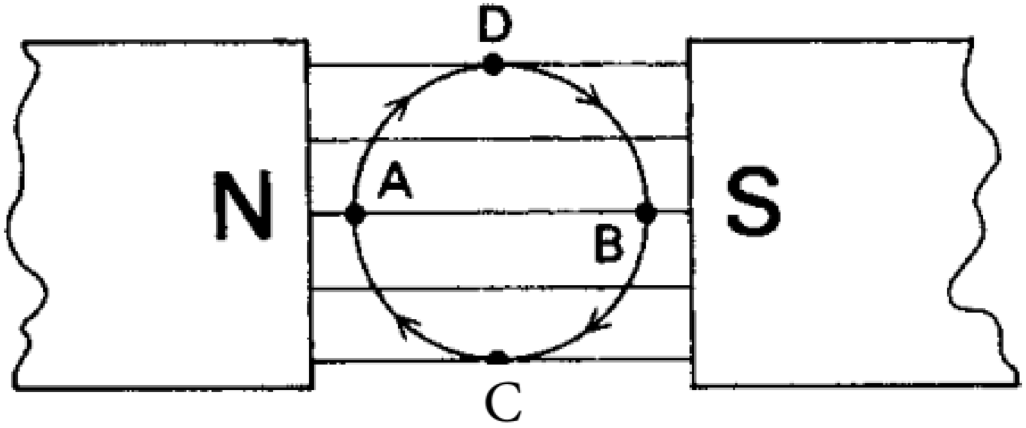
AC & DC generators.mp4

1. Induced Voltage:

- ✓ maximum at points A and B where the coil cuts through magnetic flux lines at the highest rate.
- ✓ zero at points C and D where no flux lines are cut.

$$\mathcal{E} = -N\frac{d\Phi_B}{dt} = -NAB\frac{d}{dt}(\cos \omega t) = NAB\omega \sin \omega t$$


Loop
Slip rings
N
S
External rotator
Brushes
External circuit


D
N
A
B
S
C

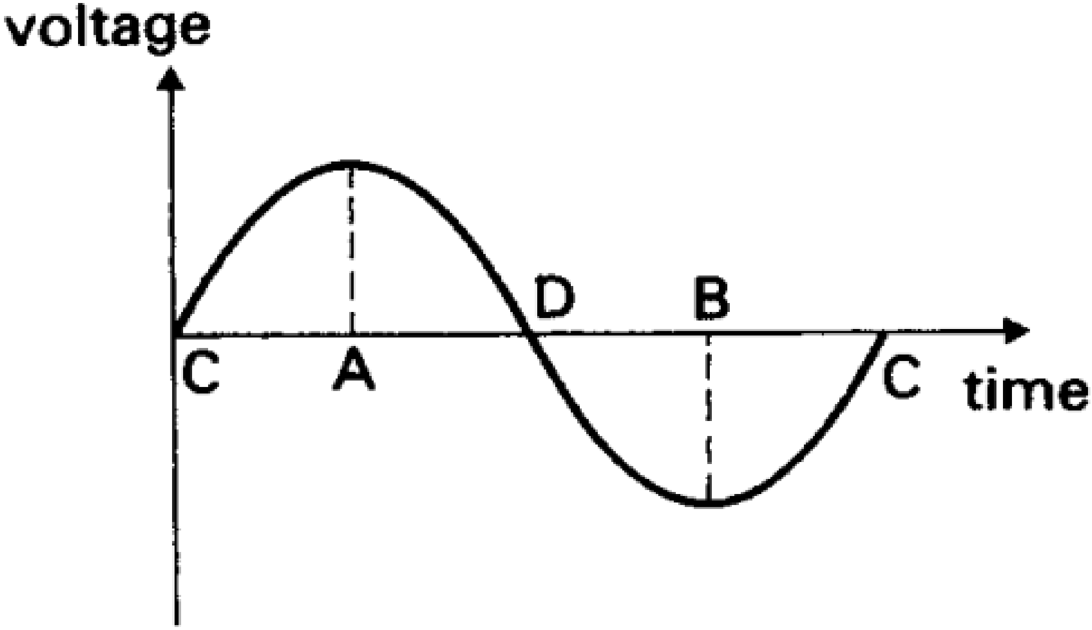
2. Waveform:

- ✓ the induced voltage varies sinusoidally with time, completing one cycle during each rotation of the coil.

3. Frequency:

- ✓ determined by the rate of rotation of the coil:

  Frequency (***f***) = Number of revolutions per second



Activity !

List and explain key parts of a generator work together to produce electricity through electromagnetic induction?

4.6 Transformers

Questions:

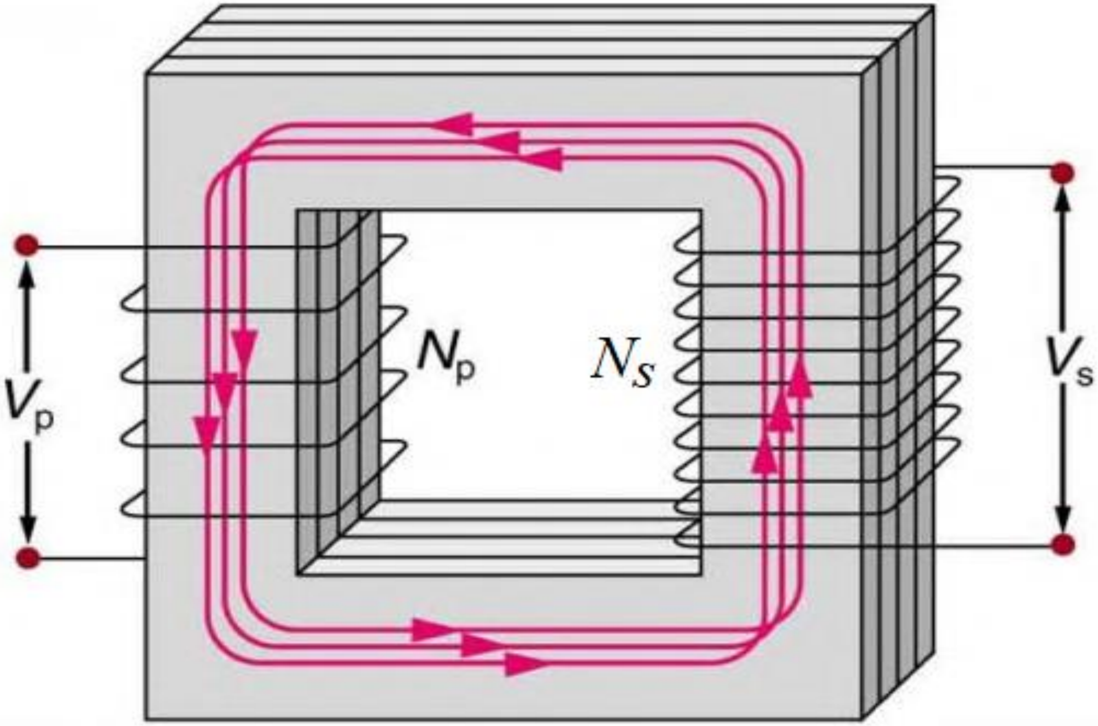
1. What are the primarily applications of transformers in power distribution systems?
2. How do transformers contribute to reducing energy losses in electrical transmission?
3. What is the function of core in the transformer?
4. How does electromagnetic induction enable transformers to transfer energy?
5. Why can a transformer work with AC but not DC?
6. How do electronic devices at home or office get variable voltage from the same power supply?
7. What devices use transformers as voltage converters?

Introduction to Transformers:

- A transformer is an electrical device that transfers electrical energy from one circuit to another via electromagnetic induction.
- It is used to either increase (step-up) or decrease (step-down) voltage levels without altering the frequency.
  - ✓ *it has no moving parts or internal mechanism to generate or alter frequency*
  - ✓ *it merely transfer energy via magnetic coupling*
- Used as electrical isolation (provide no direct contact b/n input and output).

Components of a Transformer:

- Primary Coil: receives input voltage.
- Secondary Coil: provides output voltage.
- Core: a magnetic material (e.g laminated silicon steel) that links the two coils through magnetic flux.
  - ✓ enhance magnetic coupling b/n the coils.



Working Principle:

- Transformers work on the principle of mutual induction.
  - ✓ An alternating current (AC) in the primary coil creates a changing magnetic field, which induces an emf in the secondary coil.

    Mutual Induction: The process where a changing magnetic field in one coil induces a current in another coil.

Activity!

1. Sketch a transformer and label its components.
2. Discuss how mutual induction generates voltage in the secondary coil.

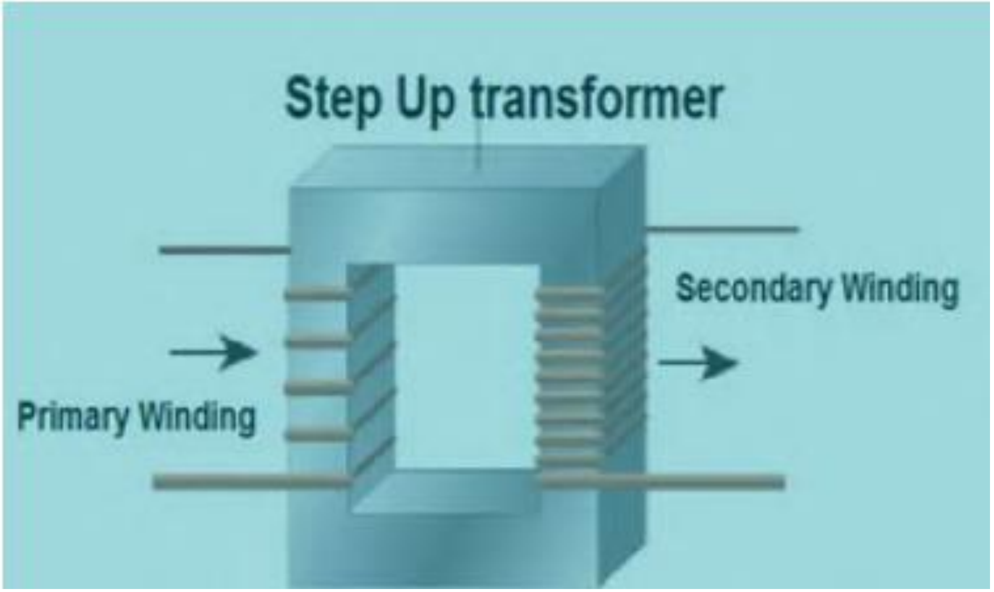
Types of Transformers

Brainstorming Questions

1. How does a transformer change the voltage of an electrical supply?
2. What are the key difference between a step-up and step-down transformer?
3. Can you think of an example where a step-up transformer might be used?
4. What is the relationship between the number of turns in the primary and secondary coils?

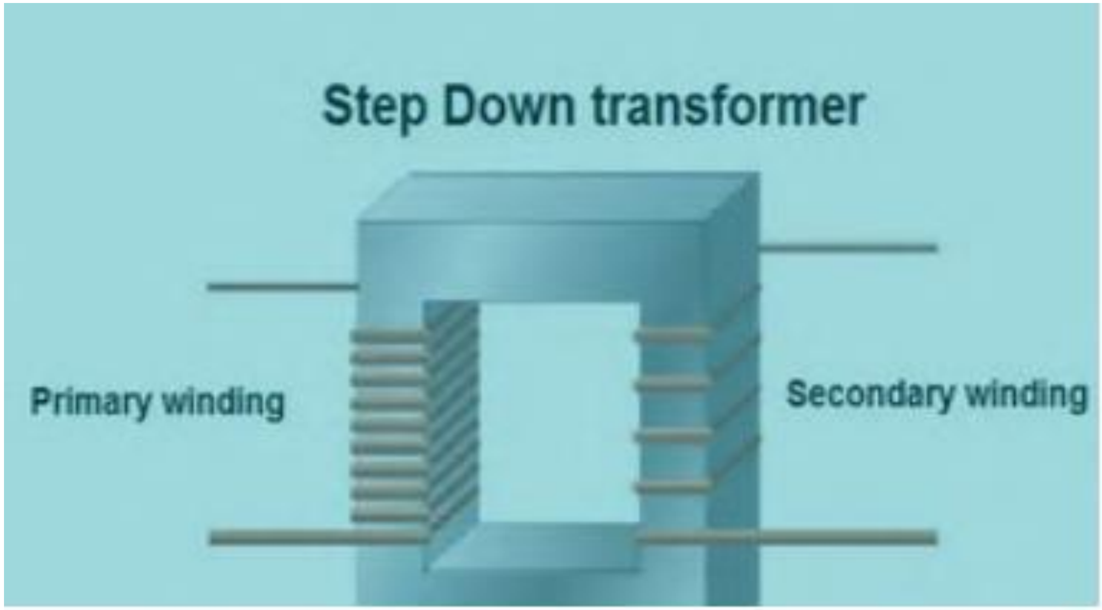
1. Step-up Transformer:

- ✓ number of turns in primary coil is less than number of turns in secondary coil.
- ✓ increases voltage from primary to secondary coil.
- ✓ decrease current.
- ✓ used in power stations for transmitting electricity over long distances



2. Step-down Transformer:

- ✓ number of turns in primary coil is greater than number of turns in secondary coil.
- ✓ decreases voltage from primary to secondary coil.
- ✓ increases current
- ✓ used in homes and electronic devices to reduce voltage for safety.



Turns Ratio (Transformation ratio):

- ✓ The turns ratio determines the voltage transformation between the primary and secondary coils:

$$\frac{N_P}{N_S} = \frac{V_P}{V_S} = \frac{I_S}{I_P}$$

Type of transformers.mp4

where; N_P & N_S:Number of turns in the primary and secondary coils.

V_P and V_S:voltage in the primary and secondary coils.

I_P and I_S: current in the primary and secondary coils.

Activity!

The primary coil of a transformer has 250 turns and its secondary coil consists of 1500 turns. If 220 V is applied to its primary coil. Calculate the voltage induced in the secondary coil. (UEE 2014)

Transformer Efficiency:

Brainstorming Question

Transformers are widely used to transfer electrical energy efficiently. However, no transformer is 100% efficient. What factors do you think contribute to energy loss in a transformer, and how can these losses be minimized?

Transformer Efficiency:

✓ is the ratio of output power to input power expressed as percentage;

$$\text{Efficiency}(\eta) = \frac{\text{output power}}{\text{input power}} \times 100\%$$

Ideal transformer:

✓ assume no energy loss; efficiency is 100%.

✓ not achievable in practice.

Real transformer

Transformer Working Animation .mp4

✓ there is energy losses.

✓ transformer efficiency can reach up to 98%.

What causes energy losses?

✓ Copper losses (I^2R): energy lost due to resistance in primary and secondary windings

- ✓ Iron losses:
  - Eddy current: current induced in the iron core create heat
  - Hysteresis loss: energy required to magnetize & demagnetize the core repeatedly.
- ✓ Leakage flux: some magnetic flux does not link the primary and secondary windings, causing loss.

Efficiency formula:

$$\eta = \frac{P_{out}}{P_{out} + Losses}$$

Practical importance:

- ✓ high-efficiency transformers reduce energy loss.
- ✓ step-up transformers are used in power grids to reduce transmission losses.

Activity!

Discuss the role of transformers in the efficient transfer of electricity.

Examples

1. A transformer steps up the voltage from 120 V to 240 V and operates at an efficiency of 100%. If the primary coil has 200 turns, how many turns are in the secondary coil?

   A. 400 turns B. 500 turns C. 600 turns D. 800 turns

2. A transformer has primary coil with 1200 loops and secondary coil with 1000 loops. If the current in the primary coil is 4 Ampere, then what is the current in the secondary coil.

Applications of Transformers in Household Appliances:

- Chargers (phones, laptops): Step-down transformers reduce high wall outlet voltage to a safe level for charging.

Figure: Mobile Phone charger.

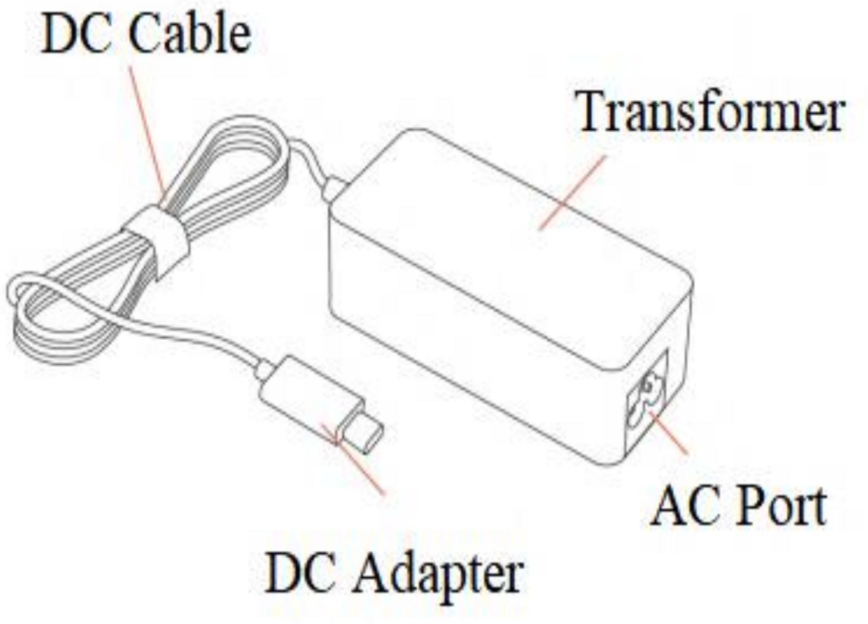


Figure: Lap top charger.

- Microwaves: Use step-up transformers to generate high voltage for cooking.
- Air conditioners: use transformer to step-down the voltage to operate the control circuit and thermostat.
- TVs: use transformer to step-down the voltage for internal circuits

Conclusion:

✓ Transformers are essential for converting voltage levels, ensuring that devices operate safely and efficiently.

4.7 Application and Safety of Electromagnetism

Applications of Electromagnetic Induction:

1. Computer Hard Drives:
   - ✓ Historically used magnetic induction to read data from spinning disks.
   - ✓ Modern drives use giant magneto resistance, a nanotechnology application involving changes in electrical resistance in response to magnetic fields.
2. Graphics Tablets:
   - ✓ Uses induction to sense the movement of a special pen across the screen.
   - ✓ A magnetic field from the pen tip induces an emf in tiny wires beneath the screen, translating movement into digital input.

Figure: A tablet with a specially designed pen to write with is another application of magnetic induction.

Other Applications of Magnets in Daily Life:

1. Electric Bells: Magnets create the force needed to ring the bell.
2. Generators and Electric Motors: Electromagnetic induction powers these devices.
3. Geographical Navigation: Magnets in compasses point towards the Earth's magnetic poles.
4. Magnetic Separation: Used to separate magnetic materials from non-magnetic materials in recycling or industrial processes.
5. Medical Field: Magnets are used to relieve pain through magnetic therapy.

Safety in Electromagnetic Fields (EMF):

EMF Types:

- Includes static fields and low-frequency waves.
- Classified as non-ionizing radiation, unlike harmful ionizing radiation like X-rays or UV rays.

EMF Safety Guidelines:

✓ Keep a safe distance from strong electromagnetic fields, especially for individuals with active body implants.

Safety Tips for Electromagnet Use:

1. Define the Load:

✓ Understand the type and number of plates to be lifted and consider any factors (e.g., air gaps) that may affect the magnet's efficiency.

2. Check for Hazards:

- ✓ Be aware of potential dangers such as falling objects or interference with medical devices due to electromagnetic fields.

3. Inspect Equipment:

- ✓ Regularly check electromagnets for electrical issues and create a checklist to ensure all safety requirements are met before use.

4. Choose the Right Electromagnet:

- ✓ Select an electromagnet that fits the specific needs of the project to ensure both safety and efficiency.

Conclusion:

- Electromagnetic induction is fundamental in modern technology, from data storage to transportation. However, safety precautions should be observed, especially in environments with strong electromagnetic fields.

The End!

Thank you!

For your attention!

For your participation!