

ELECTROMAGNETISM

PART ONE



Electromagnetism

- ❑ Electromagnetism describes the interaction between **charges, currents and the electric and magnetic fields to which they give rise.**
- ❑ Electromagnetism is the study of the properties of and relationship between electric currents and magnetic fields
- ❑ **An electric current creates a magnetic field, and a changing magnetic field will create a flow of charge.**
- ❑ The relationship between electricity and magnetism has been studied extensively.
- ❑ This has resulted in the invention of many devices which are useful to humans, for example cellular telephones, microwave ovens, radios, televisions and many more.

Examples of Electromagnet Applications



Electric Doorbells



Electric Locks

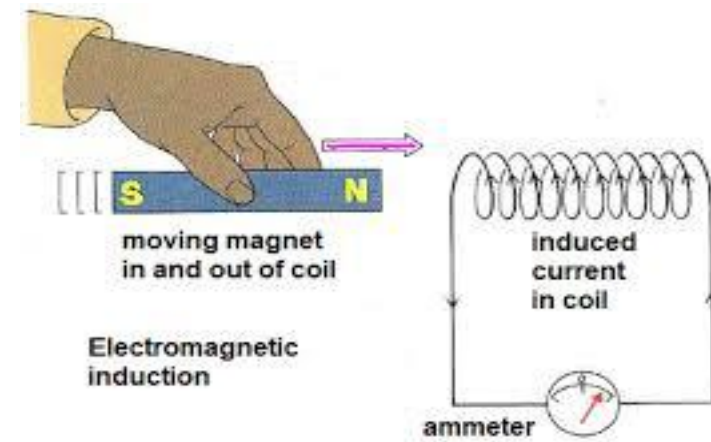
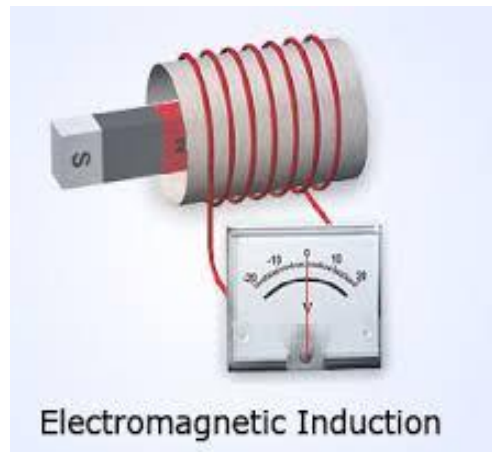
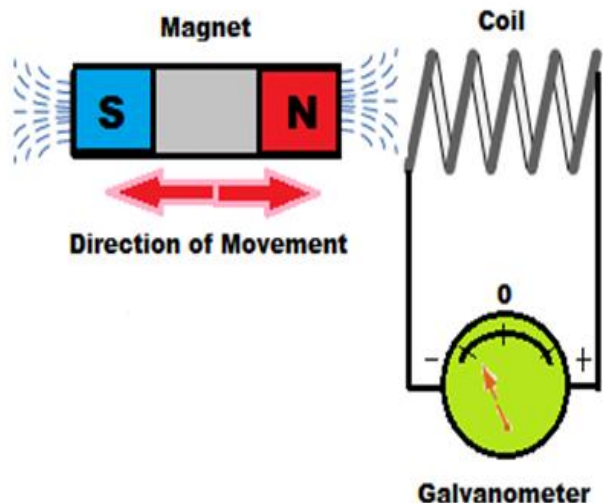


Loudspeakers

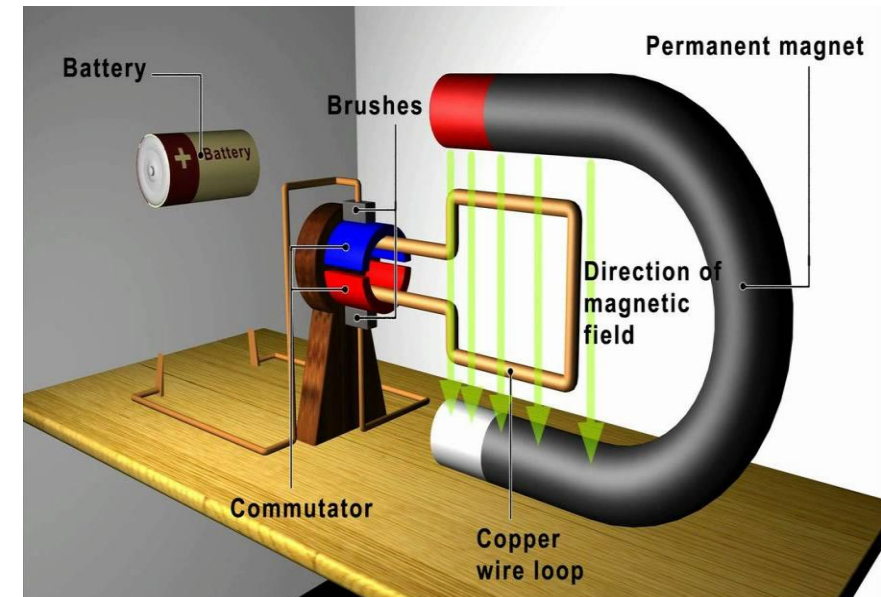


Earphones

- If a magnet is **moved relative to a coil**, an electric current is induced in the circuit.
- **When there is a change in magnetic field around a coil or conductor, current is induced.**
- This process is called **electromagnetic induction**
- An emf (electromotive force) is produced which causes a flow of current in a closed circuit.
- **There is only an induced current while there is movement of the magnet relative to the coil & vice versa. No current is induced if neither coil nor magnet are held stationary**



- Electromagnetic induction is put into practical use in the construction of electrical generators, which use mechanical power to move a magnetic field past coils of wire to generate voltage.

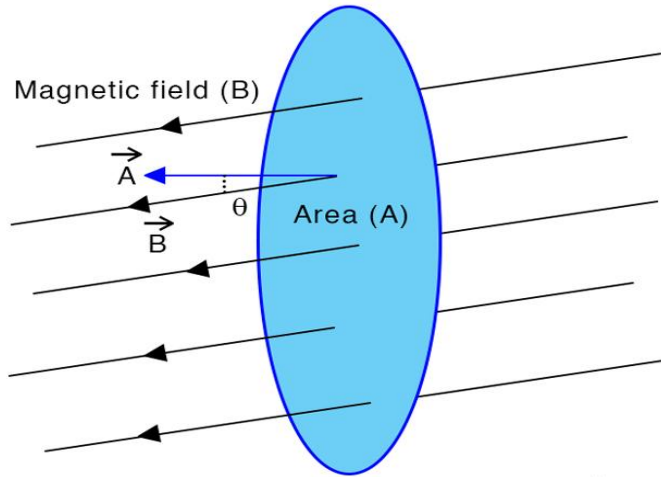


Magnetic flux

- ❖ Magnetic flux (ϕ – pronounced fie) means the total magnetic field that passes through a loop of wire. It is a measure of the field lines passing through the loop and is measured in weber (Wb)
- ❖ It is the product of the component of the magnetic field ($B\cos\theta$) perpendicular to a surface and the area (A) of the surface the field passes through

Magnetic Flux Equation

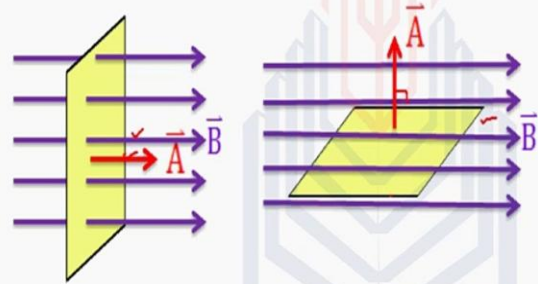
Flux = ϕ = $BA \cos \theta$



“Magnetic flux Φ_B is the number of magnetic field lines passing through a certain area”

$$\phi_B = \vec{B} \cdot \vec{A}$$
$$\phi_B = BA \cos \theta$$

θ = angle between vectors $\vec{B}$ and $\vec{A}$



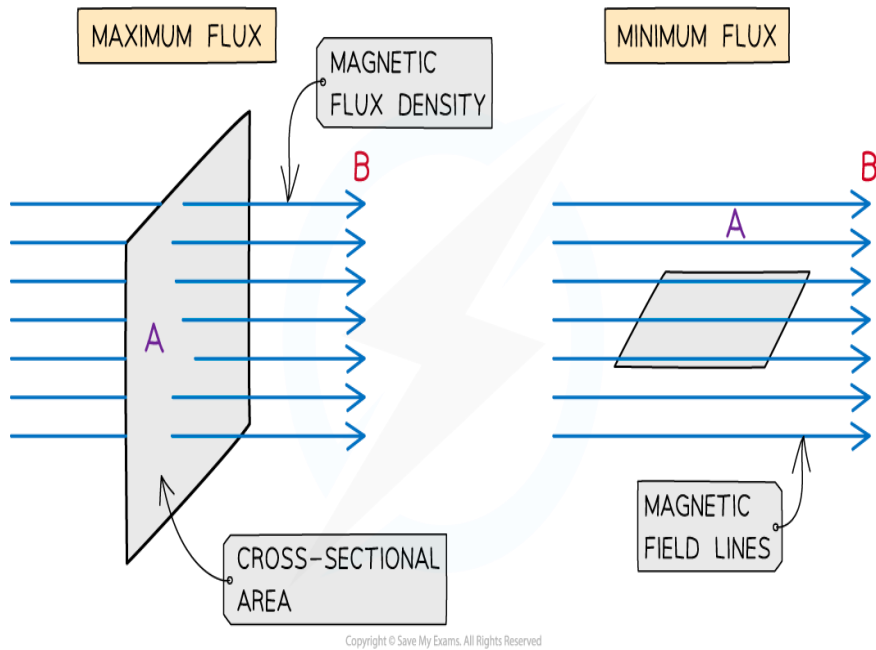
$$\phi_B = BA \cos 0^\circ$$
$$\phi_B = BA$$

Maximum flux

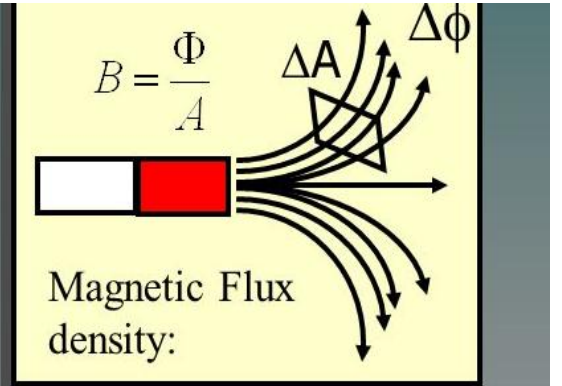
$$\phi_B = BA \cos 90^\circ$$
$$\phi_B = 0$$

Magnetic Flux Density

- ❑ Magnetic flux density (B) is a measure of the strength and direction of the magnetic field i.e. it is the magnetic flux per square metre of area that it passes through and is measured in tesla (T).



- Magnetic flux lines are continuous and closed.
- Direction is that of the B vector at any point.
- Flux lines are **NOT** in direction of force but $\perp$.



When area A is perpendicular to flux:

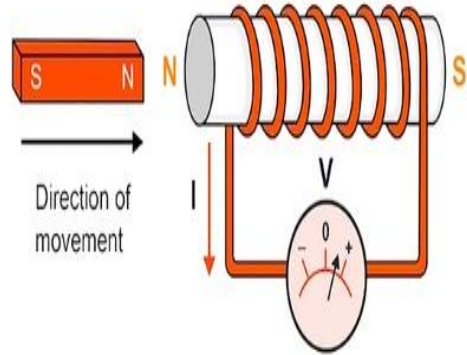
$$B = \frac{\Phi}{A}; \quad \Phi = BA$$

The unit of flux density is the **Weber per square meter**.

Faradays Law

An emf is induced in a conductor when the magnetic field surrounding it changes.

Faradays law states that, **the magnitude of the induced emf ($\mathcal{E}$) across the ends of a conductor is directly proportional to the rate of change of the magnetic flux linkage.**

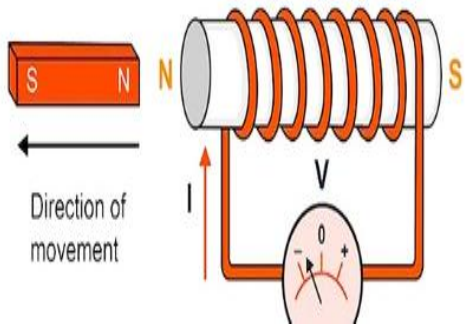


Faraday's Law of Electromagnetic Induction states that a changing magnetic field induces an electric current in a conductor.

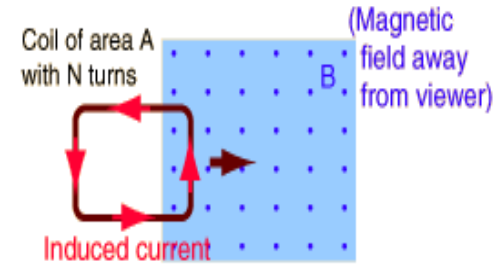
Discovered by Michael Faraday, this principle highlights the dynamic relationship between magnetism and electricity.

When the magnetic field around a conductor changes, it produces an electromotive force (EMF) that drives an electric current.

This phenomenon is fundamental to the operation of generators, transformers, and various electrical devices, playing a crucial role in the generation and transmission



Faradays Law Equation



A coil of wire moving into a magnetic field is one example of an emf generated according to Faraday's Law. The current induced will create a magnetic field which opposes the buildup of magnetic field in the coil.

Faraday's Law

$$\text{Emf} = -N \frac{\Delta\Phi}{\Delta t}$$

Lenz's Law

where N = number of turns

$\Phi = BA$ = magnetic flux

B = external magnetic field

A = area of coil

The minus sign denotes Lenz's Law.

Emf is the term for generated or induced voltage.

Emf has a negative sign because it opposes the change in flux

$$\mathcal{E} = -N \frac{\Delta\phi_M}{\Delta t}$$

Faraday's Law

N = number of loops

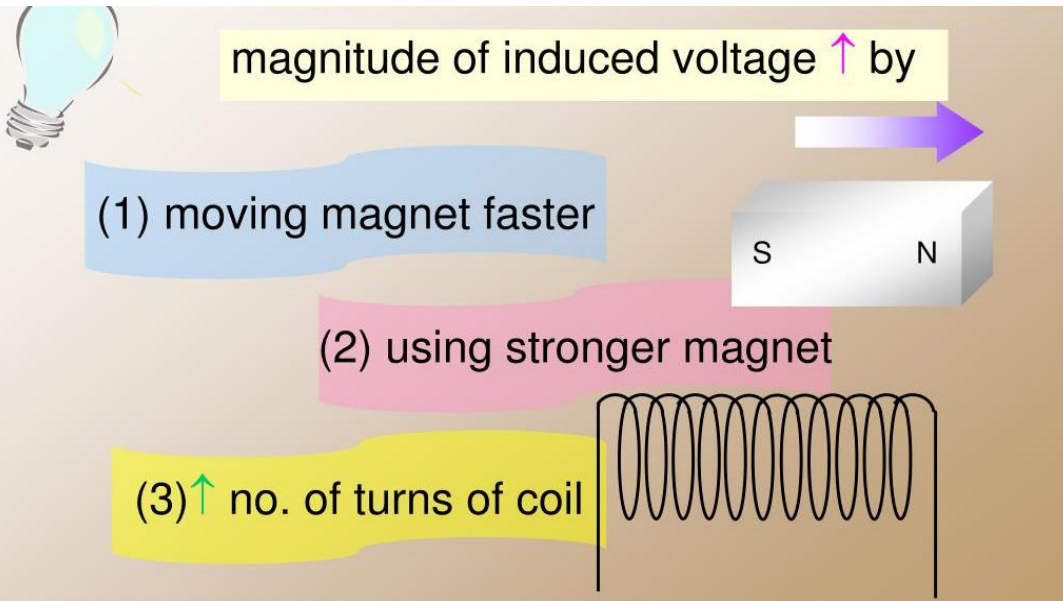
$\Delta\phi_M$ = change in magnetic flux

Δt = change in time

$\mathcal{E}$ = induced voltage (also known as emf)

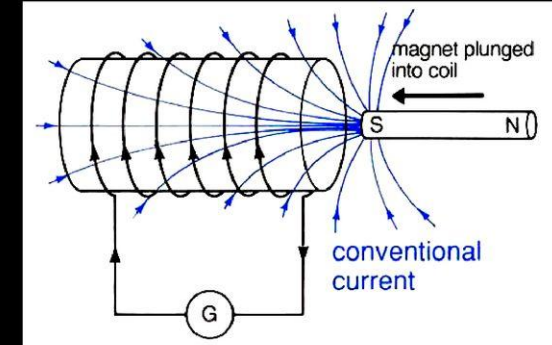
Factors influencing the magnitude of the induced current

- ❑ **The strength of the magnetic field lines** : The stronger the magnet the greater the induced current
- ❑ **The number of turns in the coil**: The greater the number of turns, the greater the induced current
- ❑ **The speed at which the magnet and coil are moved relative to each other**: The higher the speed, the greater the induced current



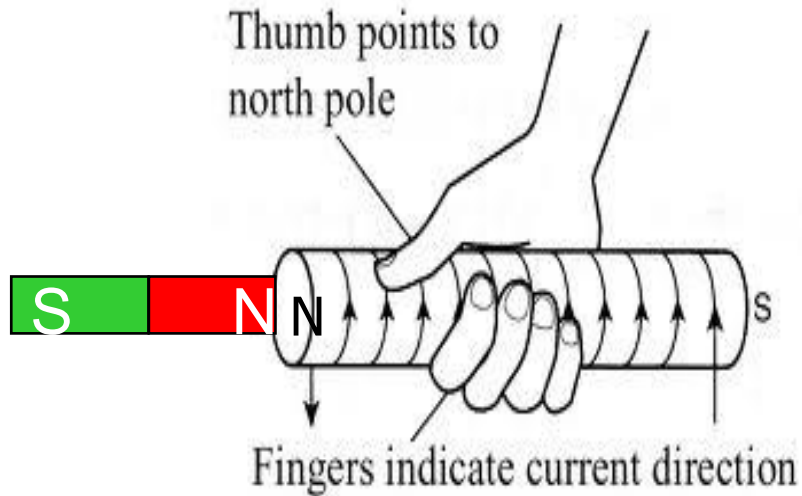
Factors affecting magnitude of induced current

1. **Number of turns of wire in the coil**
2. **Strength of magnetic field of the magnet**
3. **Rate at which magnetic field changes relative to wire (relative speed)**

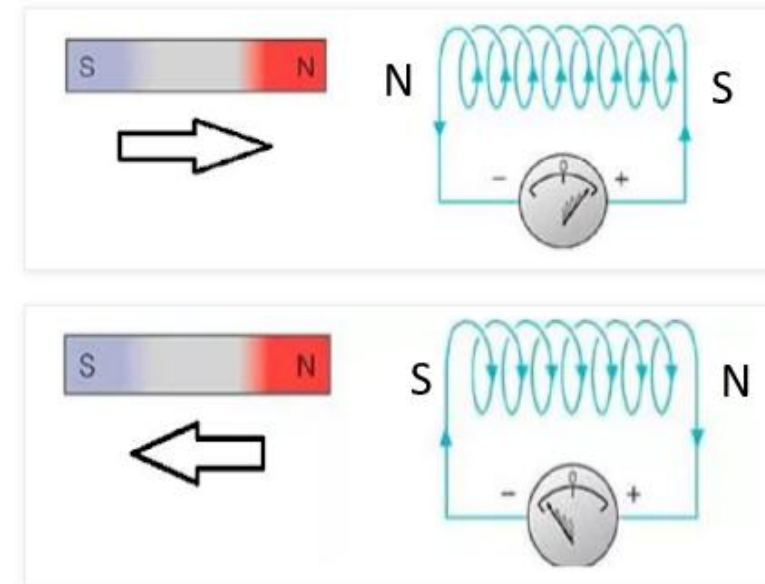
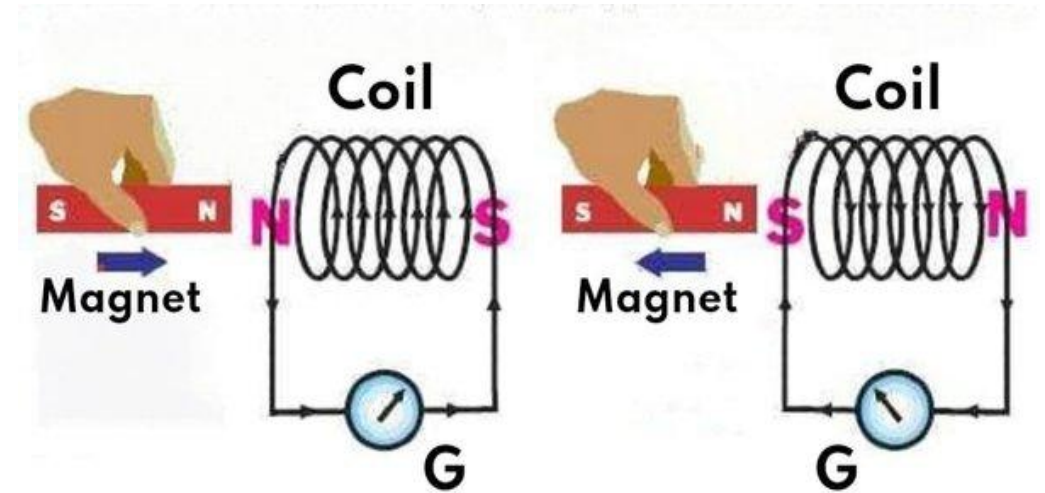


Direction of induced current

- ❖ The direction of the induced current is determined by the Right Hand Rule
- ❖ Clasp the solenoid with the thumb pointing to the induced North pole of the solenoid.
- ❖ The direction in which the fingers curl about solenoid, provides the direction of the induced current in the solenoid.
- ❖ As the N pole moves into coil – N pole formed at near end of coil – to oppose the incoming N pole and thus set up an induced current in the coil.

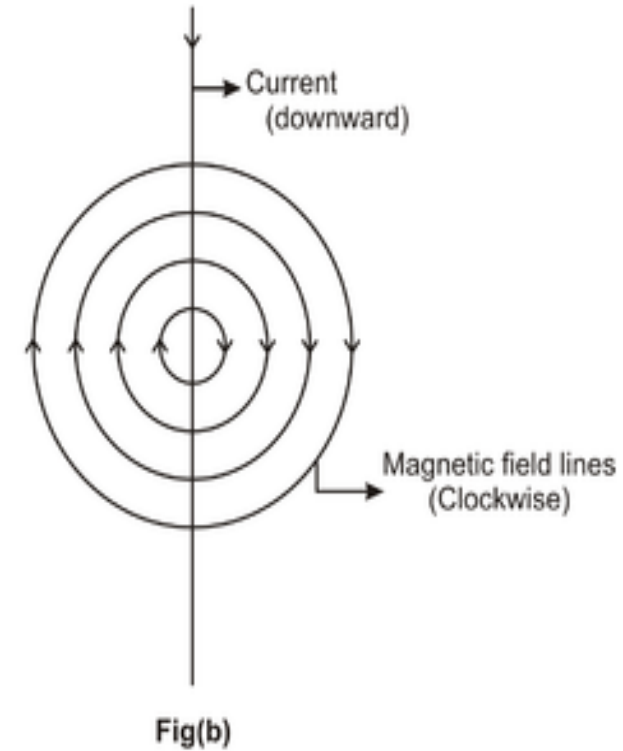
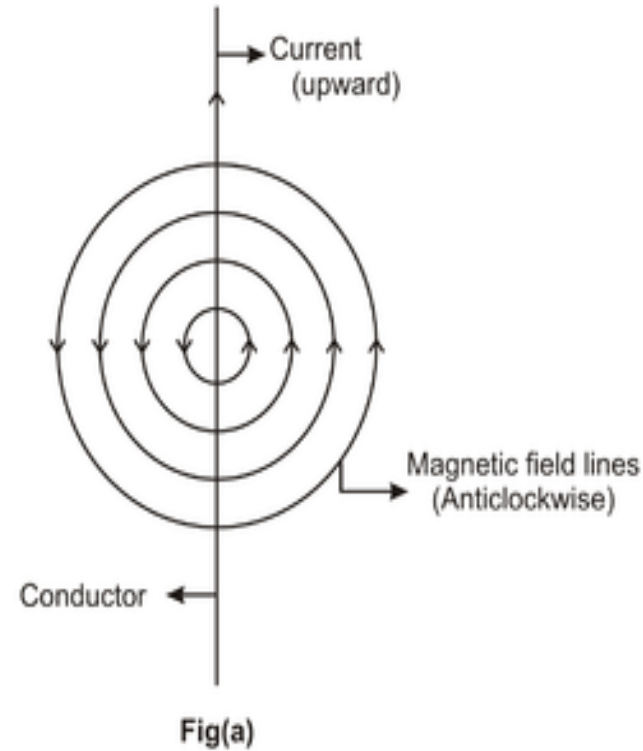


As the S pole is moved out of coil – S pole formed at near end of coil & thus a reversal of direction of current in coil.



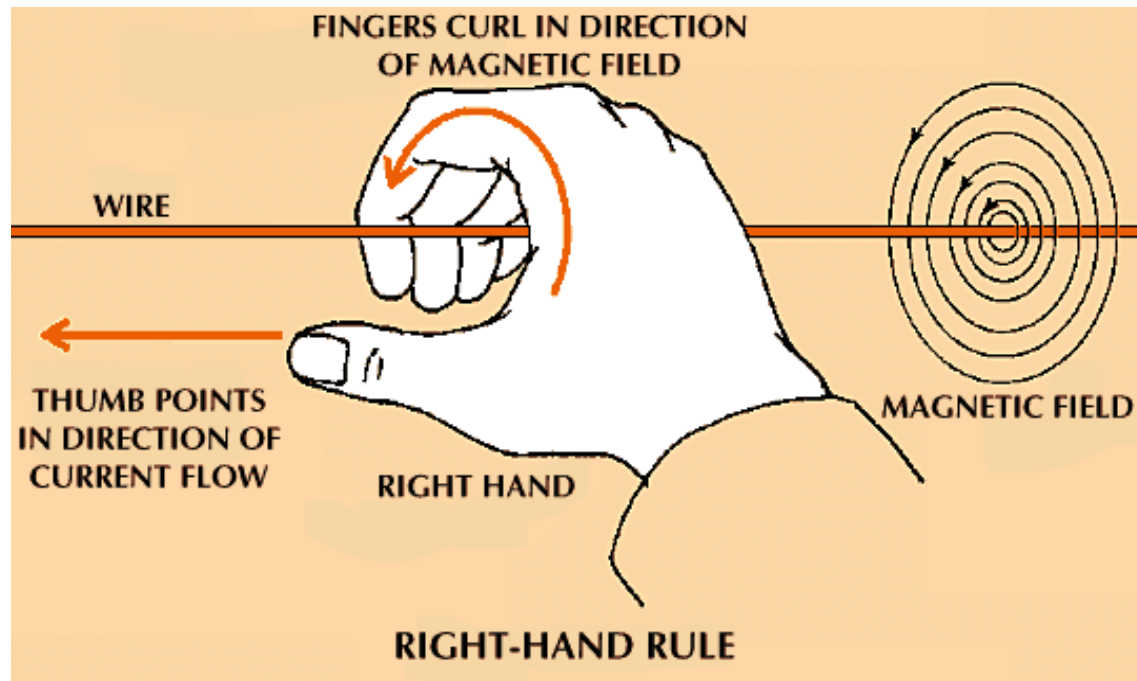
Magnetic field associated with a straight current carrying wire

- ❑ A current carrying conductor has a magnetic field around it while the current is flowing through the conductor, and this conductor is then called an electromagnet.
- ❑ Magnetic field lines produced by the current form circles with, with the wire at the center.
- ❑ They are arranged in **concentric circles** around the straight wire.
- ❑ The field lines are at **right angles to the wire**.
- ❑ The direction of the field lines is determined by the **Right Hand Rule**

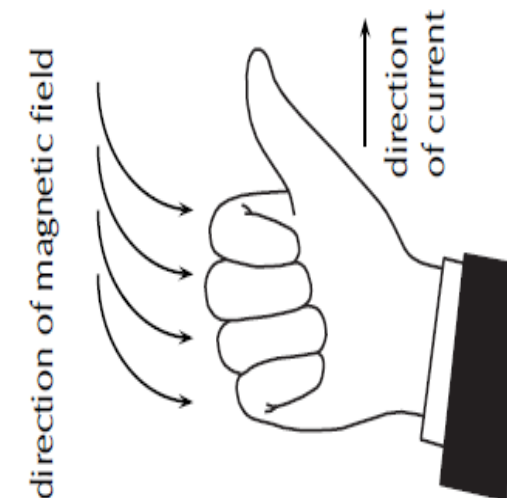
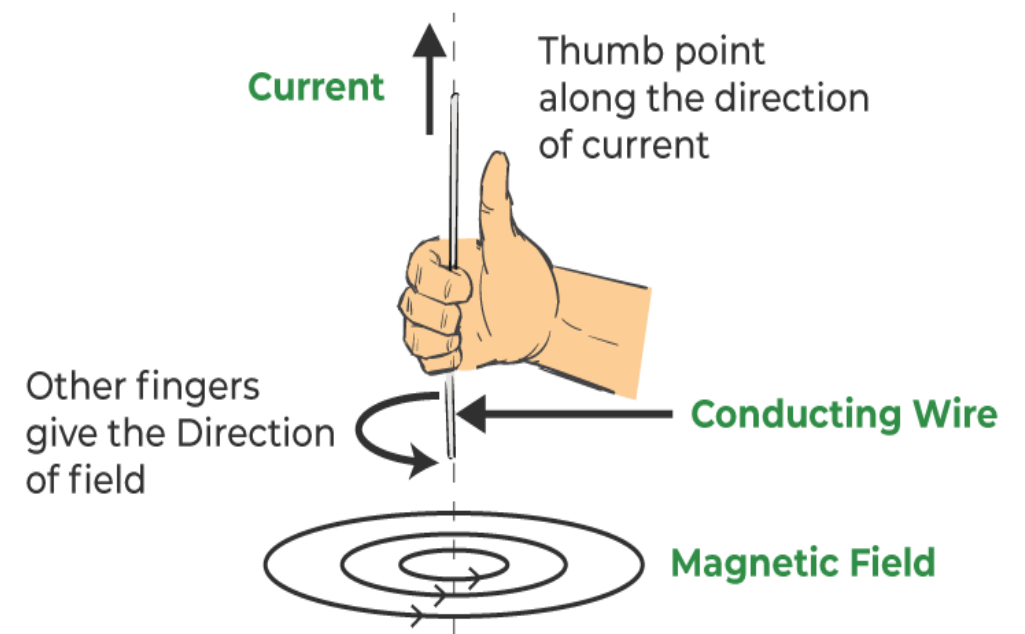


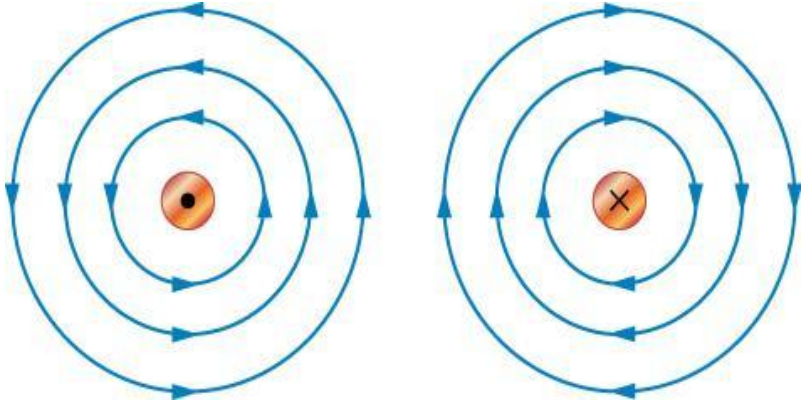
RIGHT HAND RULE

- ❖ The Right Hand Rule to determine the direction of the magnetic field associated with a current carrying conductor
- ❖ If you grasp the conductor with your right hand:
 1. The curled fingers represent the direction of the magnetic field.
 2. The thumb represents the direction of the current

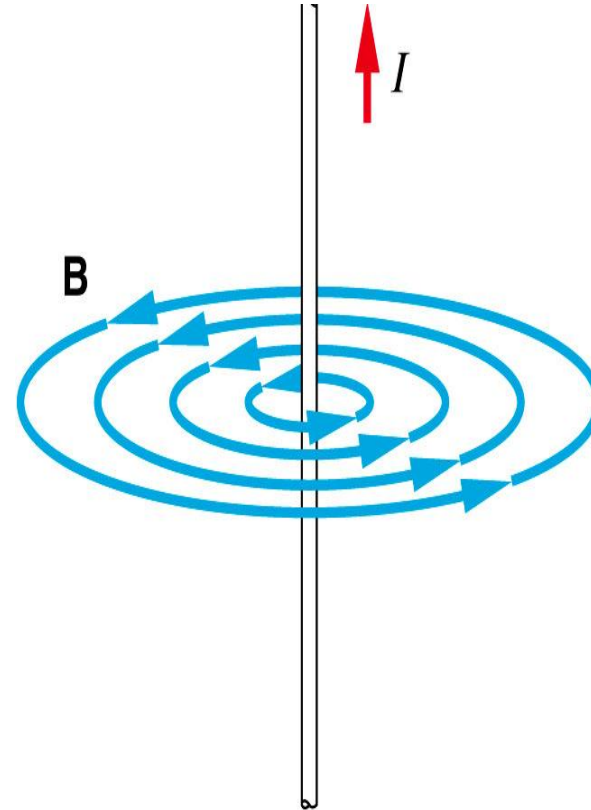
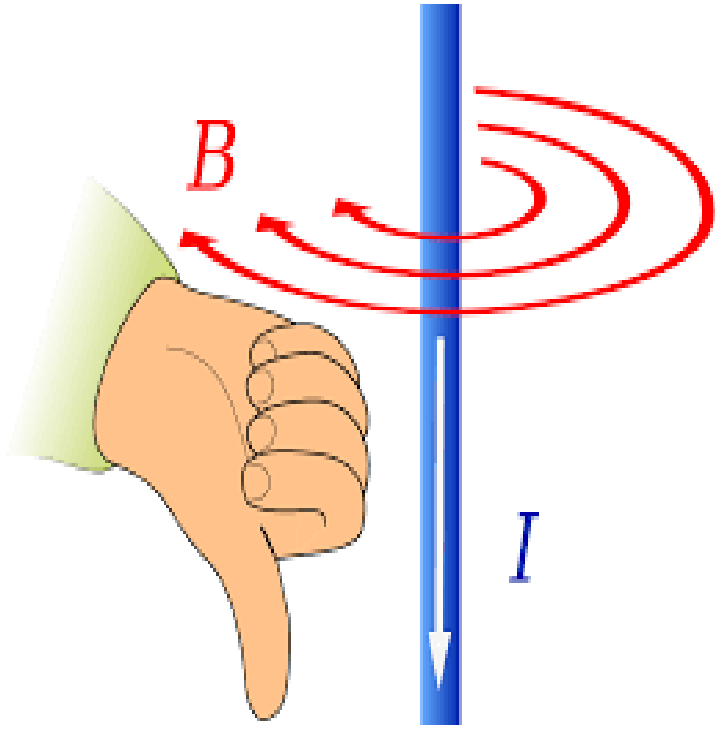


Magnetic Field due to a Current-Carrying Conductor



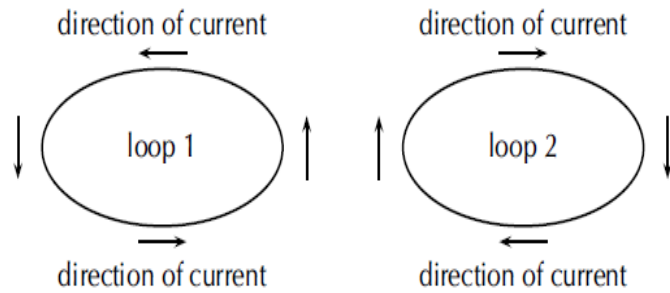


- ☐ Direct current into page (x in circle) **produces a clockwise field.**
- ☐ Current out of page (dot in circle) produces an **anticlockwise field**



Magnetic field associated with a current carrying loop (single) of wire

Consider two loops made from a conducting material, which carry currents (in opposite directions) and are placed in the plane of the page.

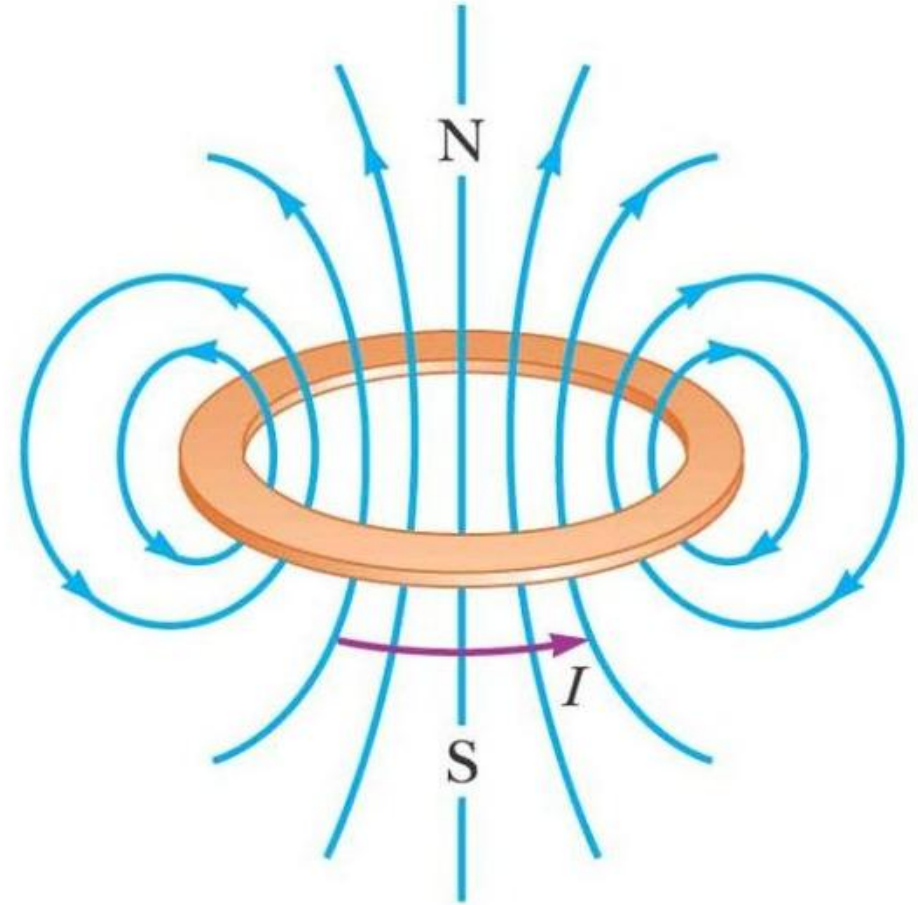


By using the Right Hand Rule

- ❖ Loop 1 has the current flowing in a counter-clockwise direction
- ❖ Loop 2 has the current flowing in a clockwise direction.

Note

1. The magnetic field lines closest to the wire are circular
2. Magnetic field lines at the center of the loop are straight and parallel to each other



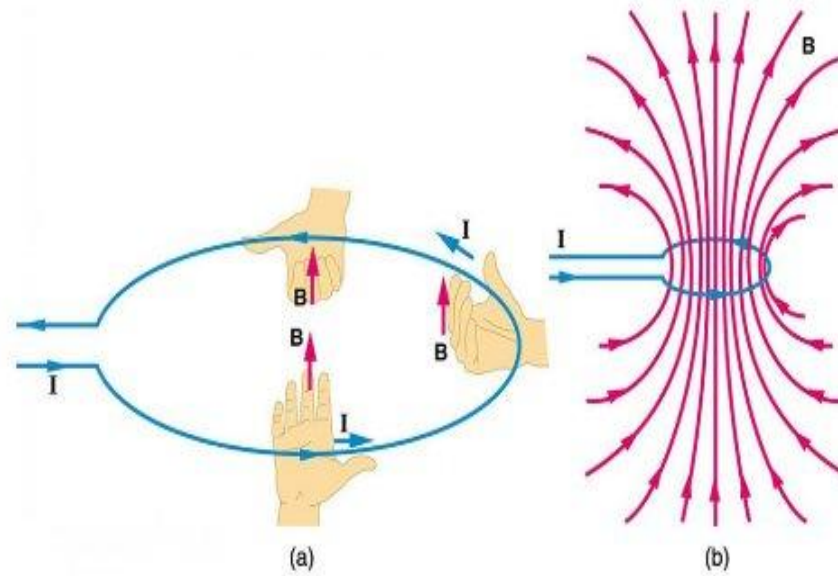
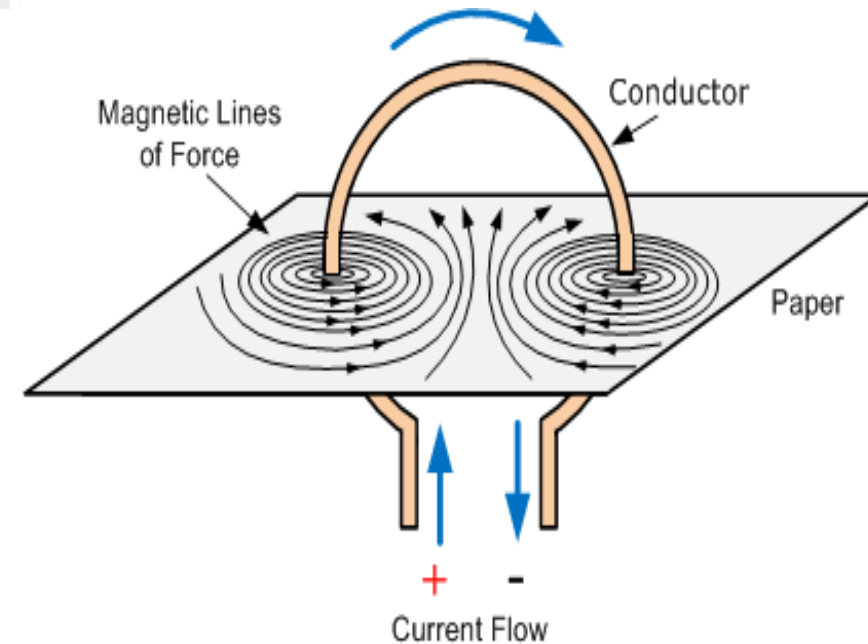
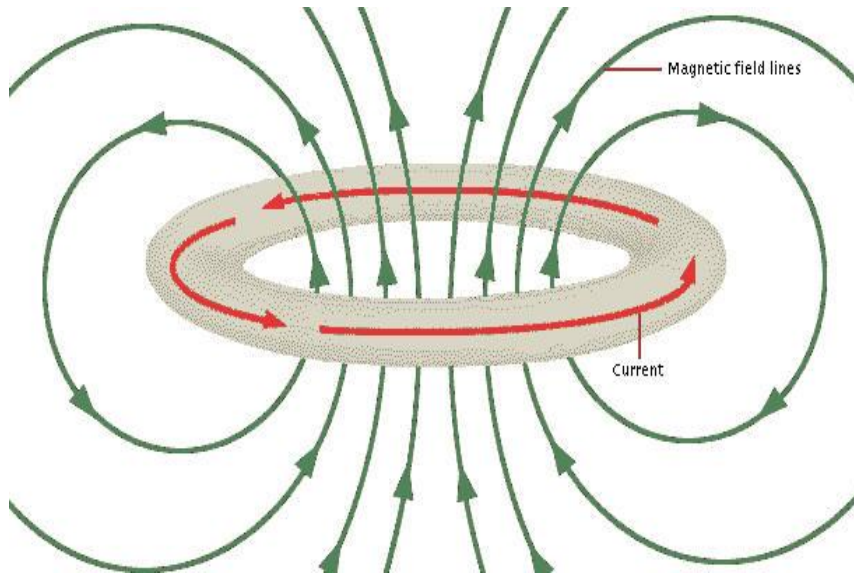
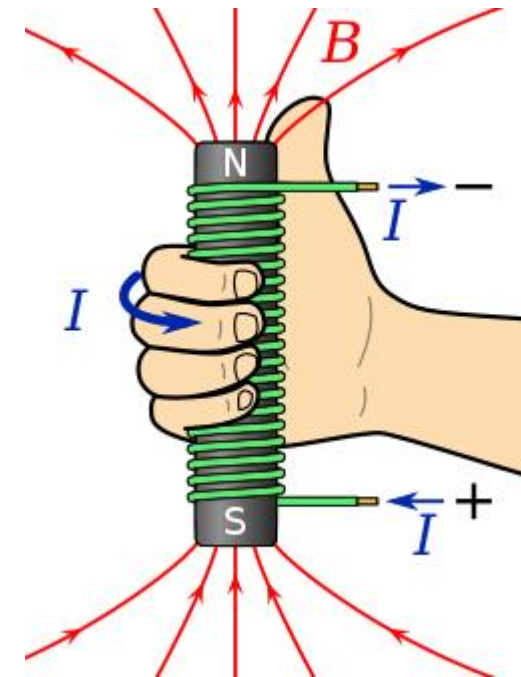
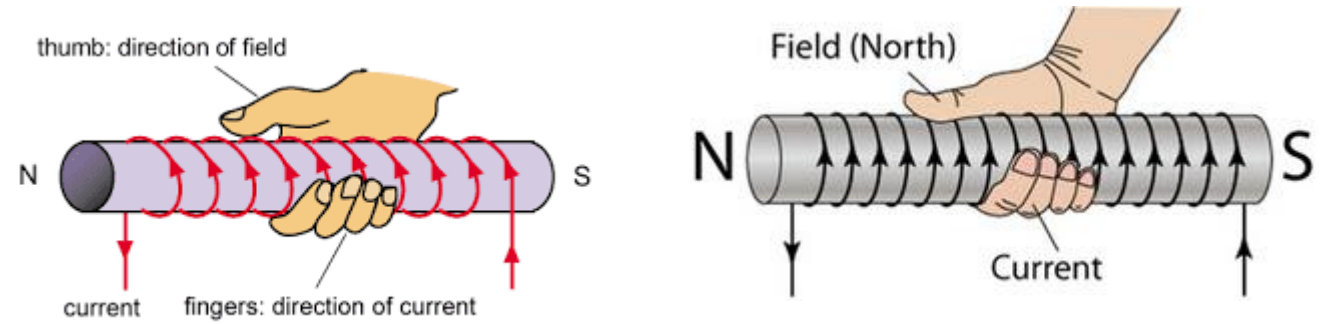


Figure 2. (a) RHR-2 gives the direction of the magnetic field inside and outside a current-carrying loop. (b) More detailed mapping with compasses or with a Hall probe completes the picture. The field is similar to that of a bar magnet.

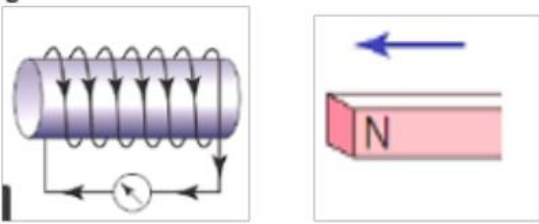


Magnetic field around a solenoid

- Magnetic field lines form closed loops
- On the outside of the solenoid, the direction of the field is from north to south like in a bar magnet
- Inside the solenoid, the direction of the field is south to north
- **The polarity of the current is determined by the Right Hand Rule**
- **The thumb is pointing at the direction of the field**
- **Curved fingers are pointing in the direction of convectional current**

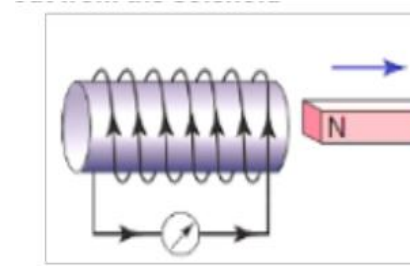


Magnet moving into solenoid



- ☐ The distance between the magnet and the solenoid decreases and so the magnetic flux inside the solenoid increases
- ☐ The magnetic field of the magnet is towards the left
- ☐ To oppose this increase towards the left, the field produced by induced current is towards the right

Magnet moving out of solenoid



- ☐ The distance between the magnet and the solenoid increases and so the magnetic flux inside the solenoid decreases
- ☐ The magnetic field of the magnet is towards the right
- ☐ To oppose this increase towards the right, the field produced by induced current is towards the left

- ❖ If the thumb points in the direction of the field, curved fingers point in the direction of current and vice versa
- ❖ The induced current flows in a direction so as to set up the magnetic field to oppose the change in magnetic flux

Environmental impact of overhead electrical cables

The construction and maintenance of above-ground power lines require clearing large swaths of land and cutting down native trees. This process disrupts local ecosystems, leading to habitat loss and fragmentation for many species. Once power lines are erected, they can also pose significant risk to local wildlife

In SA voltages in overhead power transmission lines are up to 765 kV & are dangerous

Environmental concerns are:

1. Health hazard
2. Animal hazard
3. Visual impact
4. Land use





PAST EXAM PAPERS

2023 Eastern Cape November Paper 1 Q 9

A coil with 340 turns has an area of $0,06 \text{ m}^2$. It is held with its axis coinciding with the direction of a magnetic field of strength $0,4 \text{ T}$. In order to induce an emf in the coil, it is pulled out of the magnetic field in $0,3$ seconds.

9.1 State Faraday's law of electromagnetic induction. (2)

9.2 Mention TWO ways in which the magnitude of the induced emf can be increased. (2)

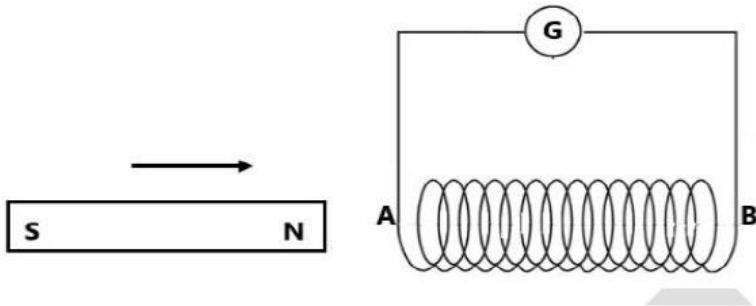
9.3 Calculate the:

9.3.1 Magnetic flux linkage (3)

9.3.2 Magnitude of the induced emf (3)

2021 Gauteng November Exemplar Paper 1 Q 6

The following diagram shows a solenoid **AB** connected to a galvanometer (able to record very small currents). The magnet is now moved as indicated.



6.1 State *Faraday's law of electromagnetic induction*, in words. (2)

6.2 State what will happen to the reading on the galvanometer when:

6.2.1 The magnet is pushed into the solenoid (1)

6.2.2 The magnet is held still inside the solenoid (1)

6.3 The magnet is moved into the solenoid.

6.3.1 Identify the polarity of point **A** on the solenoid. (1)

6.3.2 Indicate the direction a current will flow in the solenoid:

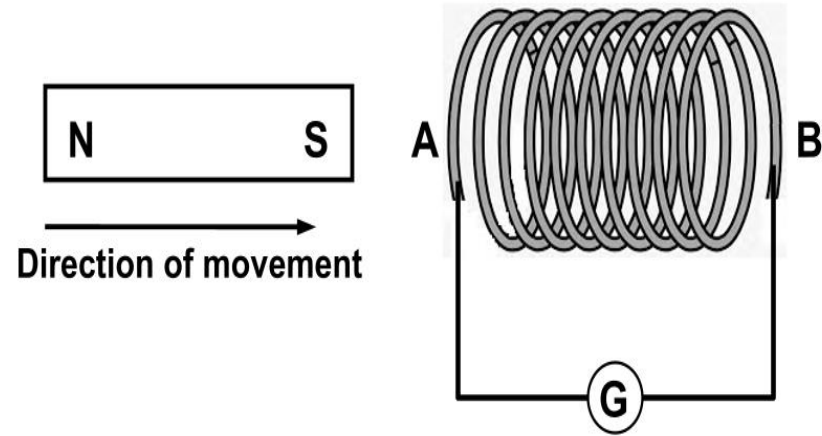
A to B or **B to A**. (2)

6.3.3 Explain the rule and how you used it to get the answer to QUESTION 6.3.2. (2)

2022 KwaZulu Natal November Paper 1 Q 4

4.1 State Faraday's Law of Electromagnetic Induction in words (2)

4.2 The SOUTH Pole of a magnet is inserted on the LEFT-HAND side of a solenoid as shown below



4.2.1 What is the polarity (NORTH POLE or SOUTH POLE) of
The left hand side of solenoid (A) as the bar magnet approaches (1)

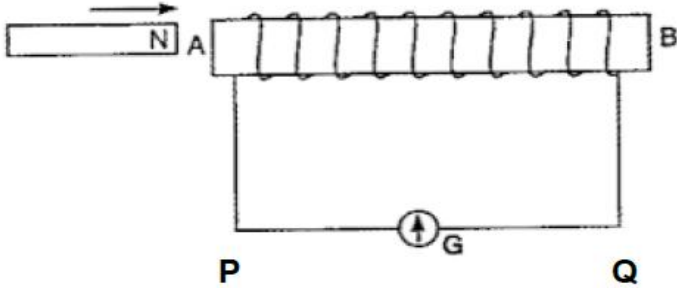
4.2.2 In which direction does the induced current flow in the coil?
Write down A to B or B to A. (2)

ELECTROMAGNETISM

PART TWO

2025 Eastern Cape November Paper 1 Q 8

The north pole of a magnet is pushed into a solenoid as shown in the diagram below.



The magnitude of the induced emf across the end of a conductor is directly proportional to the rate of change in the magnetic flux linkage with the conductor.

8.1 What is the polarity of the magnetic field of the solenoid at point A? (2)

8.2 In which direction will the current in the galvanometer deflect? Write down TOWARDS P or TOWARDS Q. (2)

8.3 A coil with 350 turns has an area of $0,08 \text{ m}^2$. It is held with its axis coinciding with the direction of a magnetic field of strength $0,6 \text{ T}$. In order to induce an emf in the coil, it is pulled out of the magnetic field in $0,25$ seconds.

8.3.1 State Faraday's law of electromagnetic induction. (2)

8.3.2 Mention TWO ways in which the magnitude of the induced emf can be increased. (2)

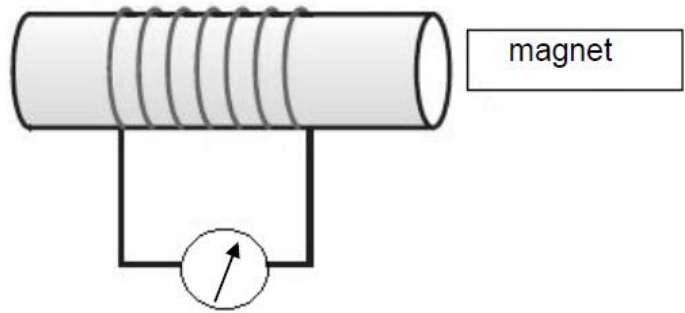
Calculate the:

8.3.3 Magnetic flux linkage (3)

8.3.4 Magnitude of the induced emf (3)

2015 November Paper 1 Q 10

10.1 The arrangement of apparatus to demonstrate Faraday's law of electromagnetic induction is shown below.



10.1.1 State Faraday's law of electromagnetic induction in words. (2)

10.1.2 State TWO ways in which the deflection on the galvanometer can be increased. (2)

10.2 A coil with area $0,6 \text{ m}^2$ is held with its axis coinciding with the direction of a magnetic field of strength $0,4 \text{ T}$.

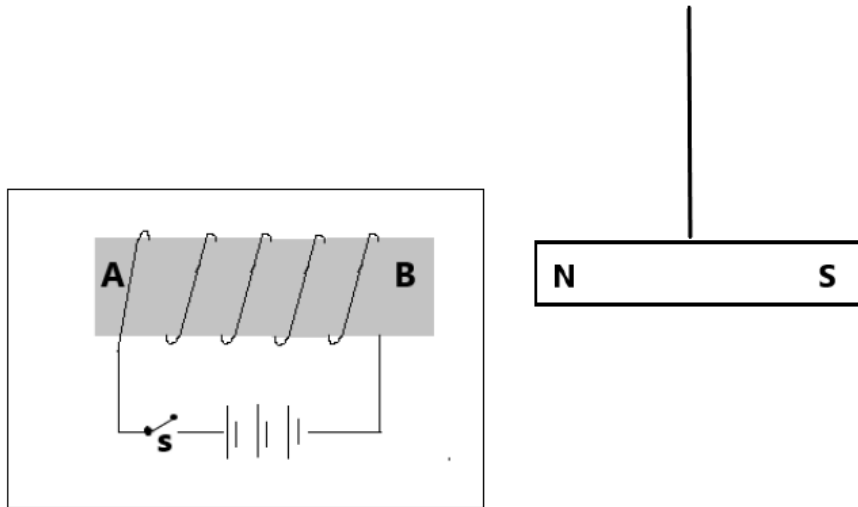
10.2.1 Calculate the magnetic flux linkage. (3)

In order to produce an emf of 9 V , the area of the coil, with its axis coinciding with the direction of a magnetic field, is halved from $0,6 \text{ m}^2$ to $0,3 \text{ m}^2$ in 2 minutes.

10.2.2 Calculate the number of turns in the coil. (4)

2022 Gauteng November Paper 1 Q 6

The solenoid on the left, connected to a battery is placed close to the bar magnet on the right, suspended on a light inextensible string and allowed to move freely, is shown in the diagram below.



6.1 State *Faraday's law of electromagnetic induction* in words. (2)

6.2 In which direction will the suspended magnet move when the switch, **S**, in the circuit of the solenoid is closed? Write only TOWARDS, AWAY FROM, REMAINS AT THE SAME PLACE.

Explain why this will happen. (3)

6.3 Name THREE changes that can be made to the system on the left to increase the effect on the magnet. (3)

2019 Eastern Cape November Paper 1 Q 10

An emf of 0,25 V is induced in a solenoid of 200 turns when it is pulled out of a magnetic field of 8 T at an angle θ in 0,01 second. The radius of the solenoid is 1 mm.

10.1 State Faraday's law in words. (2)

10.2 Calculate the ...

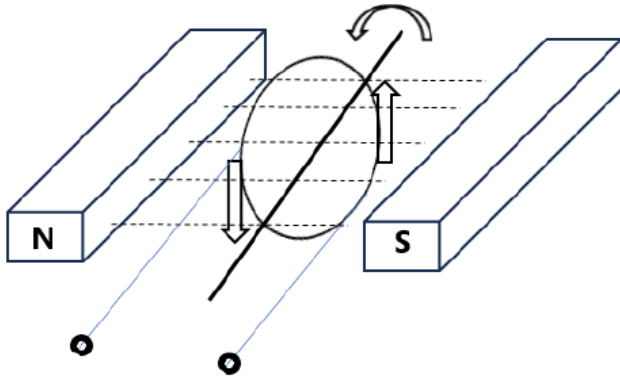
10.2.1 change in magnetic flux linkage (Φ) with the solenoid. (3)

10.2.2 angle θ at which the solenoid is pulled out of the magnetic field. (4)

10.3 A second solenoid of a bigger cross section is now pulled out of the same magnetic field at the same angle. How will the emf induced in the second solenoid compare with that in the first solenoid? Write only INCREASE, DECREASE or REMAIN THE SAME. (1)

2024 Gauteng June Paper 1 Q 6

A coil with a diameter of 0,6 m contains 60 turns and lies so that the magnetic field strength is at its maximum of +0,15 T. The field then changes to its minimum in 1,6 s. ($A = \pi r^2$)



6.1 State *Faraday's Law of Electromagnetic Induction* in words. (2)

6.2 Calculate:

6.2.1 The change in the magnetic flux in the loop. (4)

6.2.2 The average induced emf in the loop in 1,6 s. (3)

6.3 If the coil is now rotated in 1,8 s, how would it change the induced emf? Write only INCREASE, DECREASE or REMAIN THE SAME. Explain the answer. (3)

2016 KwaZulu Natal September Paper 1 Q 3

A rectangular coil consisting of 150 turns has the dimensions 25 cm by 30 cm. It is in a uniform, 1,20 T, magnetic field, with plane of the coil parallel to the field. In 0,2s, it is rotated so that the plane of the coil is perpendicular to the field

3.1 State *Faraday's Law of Electromagnetic Induction* in words (2)

3.2 Calculate the:

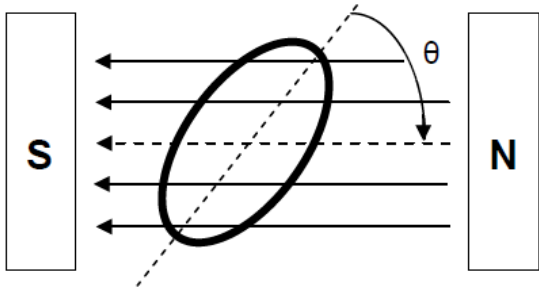
3.2.1 Change in magnetic flux through the coil during this Rotation (3)

3.2.2 emf induced in the coil during this rotation (3)

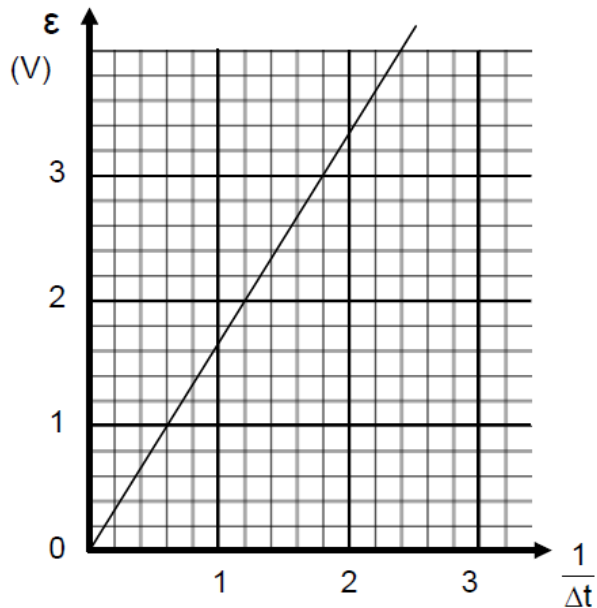
3.2.3 current induced in the coil during this rotation if the coil is connected to a resistor of 50 Ω (3)

2017 November Paper 1 Q 9

An induction coil of area $48,6 \text{ cm}^2$ and 200 windings is rotated clockwise in a constant magnetic field of magnitude $2,4 \text{ T}$. Refer to the diagram below.



The graph below shows how the induced emf varies with the inverse of time.



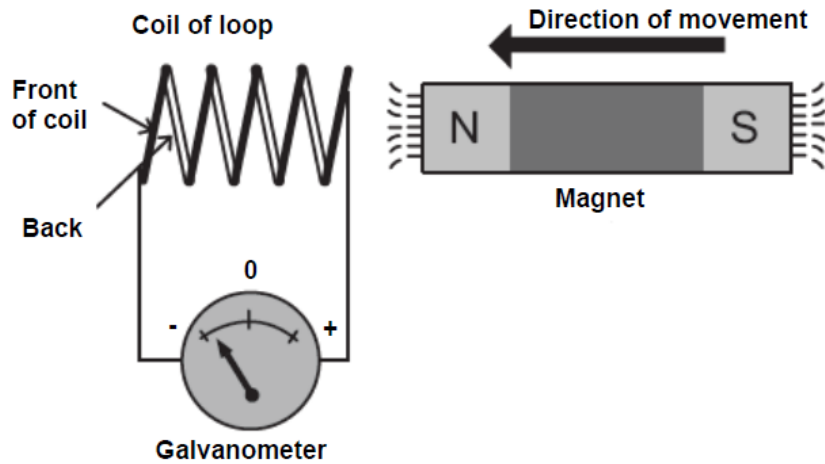
9.1 State *Faraday's law* in words. (2)

9.2 Use the information in the graph to calculate the change in magnetic flux. (5)

9.3 The coil rotates through an angle θ to a position where the magnetic flux becomes zero. Calculate angle θ . (4)

2023 Gauteng November Paper 1 Q 8

A magnet is brought near a solenoid or coil as shown in the diagram below.



8.1 State *Faraday's law of Electromagnetic induction*. (2)

8.2 Why does the galvanometer deflect as the magnet is brought close to the coil? (1)

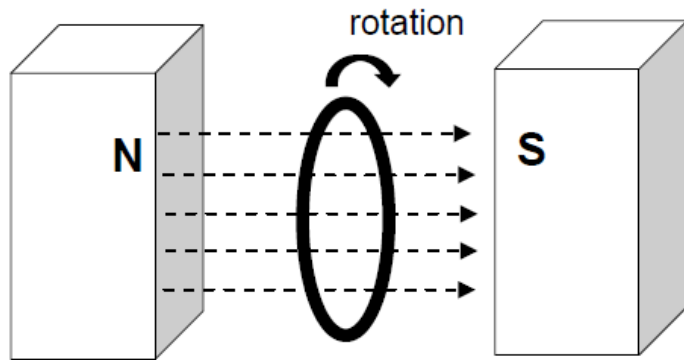
8.3 What rule can be used to predict the direction of the induced current? (1)

8.4 Give THREE ways in which the strength of the induced current can be increased. (3)

8.5 A coil with 200 windings (turns) is rotated so that the magnetic flux linkage with each winding changes from 5×10^{-4} Wb to 1×10^{-4} Wb in 0,2 s. Calculate the induced emf in the coil. (3)

2016 November Paper 1 Q 9

A circular coil with 250 windings (turns) and a radius of 0,04 m, is rotated clockwise inside a magnetic field with a field strength of 3,2 T.



Write down only THE SAME AS, LARGER THAN or SMALLER THAN. (1)

9.4.2 Explain the answer to QUESTION 9.4.1. (2)

9.1 Calculate the magnetic flux through the coil at the position indicated on the diagram, where the coil is perpendicular to the field. (3)

9.2 If the coil rotates clockwise through 25° , and the potential difference induced is 2,8 V, calculate the time in which this rotation took place. (4)

9.3 Which law can be used to explain the phenomenon described in QUESTION 9.2? Name and state the law. (2)

9.4 9.4.1 If the circular coil is replaced with a square coil with a side length of 0,04 m, and the same movement is made in the same amount of time, will the induced emf be the same as, larger than or smaller than the circular coil?

2019 November Paper 1 Q 9

A coil with 200 windings and a surface area of $2,8 \times 10^{-3} \text{ m}^2$ is rotated at constant speed in a constant magnetic field of 2,5 T. An emf of 3,5 V is induced in the coil.

9.1 Consider the following statement: The magnitude of the induced emf across the ends of a conductor is directly proportional to the rate of change in the magnetic flux linkage with the conductor.

Name the law represented by the above statement. (1)

9.2 Calculate the:

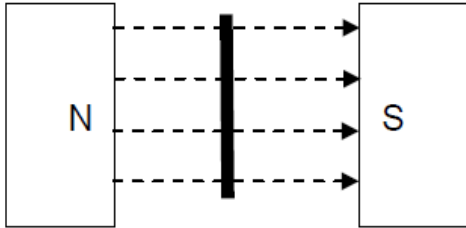
9.2.1 Change in magnetic flux if the angle of the coil relative to the magnetic field changes from 0° to 90° (3)

9.2.2 Time it takes the coil to rotate from 0° to 90° (3)

9.3 By what factor will the induced emf change if a coil with 100 windings is used under the same conditions? Give a reason for the answer. (2)

2018 November Paper 1 Q 11

A SQUARE induction coil with a side length 3 cm and 400 windings, is placed perpendicularly in a uniform magnetic field and then rotated through an angle of 45° in 0,08 s.



An emf of 7 V is induced in the coil.

11.1 State *Faraday's law of electromagnetic induction* in words. (2)

11.2 Calculate the change in the magnetic flux. (3)

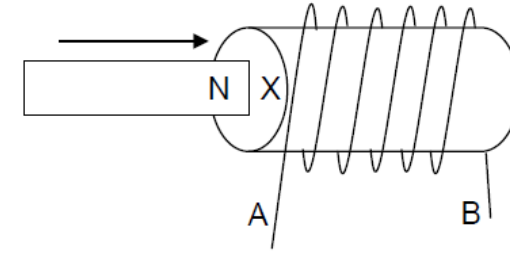
11.3 Calculate the magnitude of the magnetic field. (4)

The coil is now rotated through an angle of 45° in 0,05 s.

11.4 How will the induced emf be affected? Write only INCREASE, DECREASE or STAY THE SAME. (1)

11.5 Explain the answer to QUESTION 11.4. (1)

The north pole of a bar magnet is pushed into a solenoid, as shown in the sketch below.



11.6 Which pole will be induced at point X? Write only NORTH or SOUTH. (1)

11.7 In which direction will the induced current flow? Write only FROM A TO B or FROM B TO A. (1)

2023 Eastern Cape June Paper 1 Q 7

Consider a solenoid of 9 turns with unknown radius r .

The solenoid is subjected to a magnetic field of $0,12\text{T}$.

The face of the solenoid is perpendicular to the magnetic field. When the field is uniformly switched to 12 T over period of 2 minutes an emf of magnitude of $-0,3\text{V}$ is induced.

7.1 State Faraday's law of electromagnetic induction in

Words (2)

7.2 Calculate:

7.2.1 the change in magnetic flux (4)

7.2.2 the radius of the solenoid (4)

