Electromagnetic Induction

Electromagnetism

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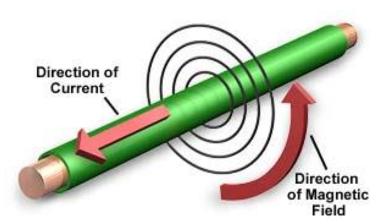
Introduction

In this lesson we are going to:

- Define electromagnetic induction.
- Perform simple experiments to demonstrate electromagnetic Induction.
- Identify the factors that affect induced electromotive force (emf).
- Explain Faraday's and Lenz's laws of electromagnetic induction.



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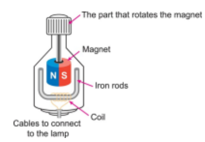
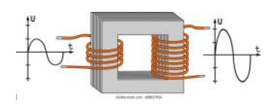
Electromagnetic Induction

- Electromagnetic induction is the process of **generating** an electric current in a conductor by **changing** the magnetic field around it.
- We can also define it as the production of electricity from magnetism.
- This happens when a conductor (like a wire) **moves** through a magnetic field or when the magnetic field around a stationary conductor **changes**.
- The electric current that is produced is called **induced current**.

- **Examples**
  - A bicycle dynamo generates electricity to power a light when the wheel spins a magnet near a coil of wire.
  - Transformers in power lines use electromagnetic induction to change voltage levels.





- Below are simple experiments to demonstrate electromagnetic induction.

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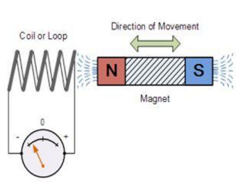
Electromagnetic Induction
experiment 1 – moving a magnet in a coil

Materials:
- A coil of wire (copper coil with many turns)
- A bar magnet
- A galvanometer (a device to detect small electric currents)

Diagram:



Steps:
1. Connect the ends of the coil to the galvanometer.
2. Move the bar magnet in and out of the coil slowly.
3. Observe the galvanometer needle.

Observation:
- When the magnet moves into the coil, the needle deflects in one direction.
- When the magnet moves out, the needle deflects in the opposite direction.
- If the magnet is still, the needle stays at zero (no current).

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Electromagnetic Induction

experiment 1 – moving a magnet in a coil

Explanation:

- Moving the magnet changes the magnetic field through the coil, inducing a current. The faster the magnet moves, the bigger the deflection (more current).

Group Assignment

- Describe an experiment that can be carried out to show that a moving magnet inside a coil induces electric current in the coil. **(6 marks)**

Galvanometer

- is a simple device that **detects** and **measures small** electric currents in a circuit.
- Its main function is **to show** the **presence** and **direction** of current flowing in a conductor.
- Below are circuit symbols of a galvanometer:

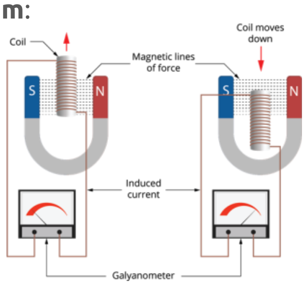
Electromagnetic Induction

experiment 2 – moving a coil in a magnetic field

Materials:

- A horseshoe magnet (U-shaped magnet)
- A small coil of wire
- A galvanometer

Diagram:



Steps:

1. Connect the coil to the galvanometer.
2. Move the coil up and down between the poles of the horseshoe magnet.
3. Watch the galvanometer needle.

Observation:

- The needle moves when the coil is moving but stays at zero when the coil is still.

Explanation:

- The coil cuts through the magnetic field lines as it moves, as such inducing a current.

Factors that affect the magnitude and direction of induced EMF

- The **induced electromotive force (emf)** is the voltage generated by electromagnetic induction.
- This emf has both **magnitude** (size) and **direction**.
- Below are factors that affect the **magnitude** of the induced emf.

1. **Speed of movement**:
   - The faster the magnet or coil moves, the greater the emf. For examples, pushing a magnet quickly into a coil produces a larger current than moving it slowly.
   - This factor is also called ***rate of change of magnetic flux***.
2. **Strength of the Magnetic Field**:
   - A stronger magnet (more magnetic field lines) induces a larger emf. A stronger bar magnet causes a bigger deflection on the galvanometer.
3. **Number of turns in the Coil**:
   - More turns in the coil mean more emf because more wire cuts through the magnetic field. A coil with 100 turns produces more emf than a coil with 10 turns.
4. **Area of the Coil**:
   - A larger coil (bigger loop area) intercepts more magnetic field lines, increasing emf.

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Factors that affect the magnitude and direction of induced EMF

- Below are factors that affect the **direction** of the induced emf.

1. **Direction of motion**
   - If a conductor moves in one direction across a magnetic field, the current flows in one direction; reversing the motion reverses the current. For example, ushing a magnet into a coil induces current in one direction; pulling it out reverses it.
2. **Polarity of the magnetic Field**
   - Switching the north and south poles of a magnet also changes the direction of the induced EMF.
3. **Orientation of the Conductor**
   - changing the orientation of a conductor in a magnetic field alters the current's direction.

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Laws of Electromagnetic Induction

- We have **two** main laws of electromagnetic induction, namely:
  - **Faraday's Law**
  - **Lenz's Law**

Faraday's Law

- In simple terms, this law states that "the amount of emf induced in a coil depends on how quickly (fast) the magnetic field through the coil changes."
- This law focuses on the amount (magnitude) of the induced current.
- If you change the magnetic field faster (e.g., move the magnet faster), you get more emf.
- If there's **no** change in the magnetic field (e.g., magnet is still), there's **no** emf.

Lenz's Law

- In simple terms, this law states that "the induced current flows in a direction that opposes the change in the magnetic field that caused it".
- This law focuses on the direction of the induced current.
- For example, If you push a magnet into a coil, the coil produces a current that creates a magnetic field that pushes the magnet back out.

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Generators & Motors

Electromagnetism

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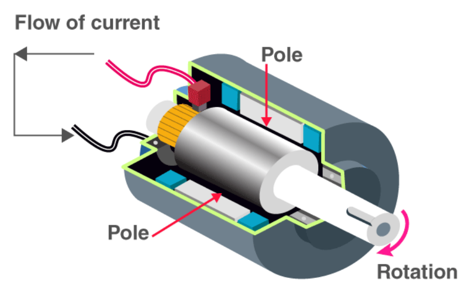
Introduction

In this lesson we are going to:

- Define a generator.
- Discuss the main types of generators.
  - AC generator
  - DC generator
- Define a motor.
- Discuss the working of a DC motor.
- Discuss Mutual Induction.



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Generator

- A generator is a device that ***converts*** **mechanical** energy into **electrical** energy using the principle of electromagnetic induction.
- There are **two** main types of generators:
  - **Alternating Current (AC)** generators.
  - **Direct Current (DC)** generators.
- **AC** is an electric current that ***changes direction periodically*** while, **DC** is an electric current that flows in ***one constant direction.***

AC Generator

- The AC Generator's input supply is mechanical energy supplied by steam turbines, gas turbines and combustion engines.
- The output is alternating electrical power in the form of alternating voltage and current.
- The figure (next slide) below shows a simple structure illustration of an AC generator.

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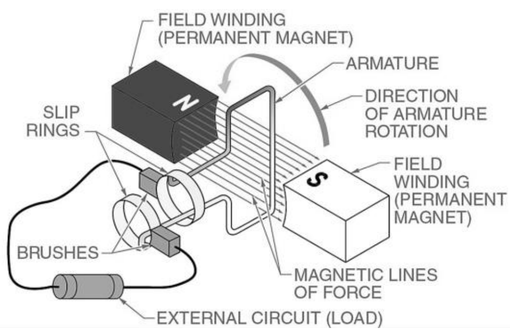
Generator



Structure of an AC generator

- **Magnet**:
  - Provides a magnetic field, either using permanent magnets or electromagnets.
- **Armature**
  - A coil of wire wound around an iron core, which rotates within the magnetic field.
- **Slip Rings**:
  - Two metal rings connected to the ends of the coil, which rotate with the armature.

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Generator

Structure of an AC generator

- **Carbon Brushes**:
  - Conductors that maintain electrical contact with the slip rings to transfer current to the external circuit.
- **External Circuit**:
  - Connected to the brushes to deliver the generated AC to a load (e.g., a bulb or resistor).

Activity 1

Fig 10.1 shows the structure of a simple a.c. generator.

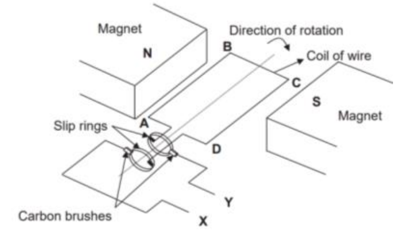

Fig 10.1

The two ends of the wires, **X** and **Y** are connected to a Cathode Ray Oscilloscope. Sketch the wave that will be displayed on the CRO screen.

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Generator

How an AC generator works

- The AC generator operates based on **Faraday's Law of Electromagnetic Induction**, which states that an EMF is induced in a conductor when it experiences a changing magnetic field.
- The armature (coil) is rotated mechanically (e.g., by a turbine or engine) within a magnetic field of the permanent magnets.
- As the coil rotates, the magnetic flux through the coil changes continuously, inducing an EMF in it.
- The direction of the induced current reverses every half-rotation of the coil, producing an alternating current that varies sinusoidally with time.
- The slip rings ensure continuous contact with the external circuit, allowing the alternating current to flow out.

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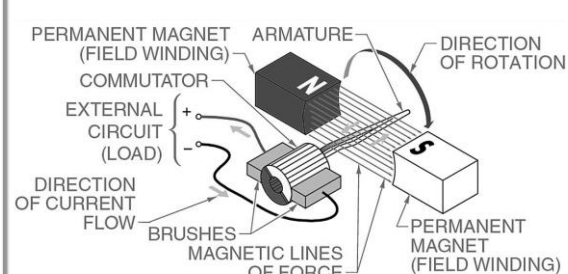
Generator

DC Generator

- A **DC generator** is a device that converts **mechanical energy** (from rotation) into **direct current (DC) electricity** using electromagnetic induction.
- It is also called a **dynamo**.
- The structure of a DC generator is similar to that of an AC generator with minor differences.
- The figure on the right shows a structure illustration of a DC generator.



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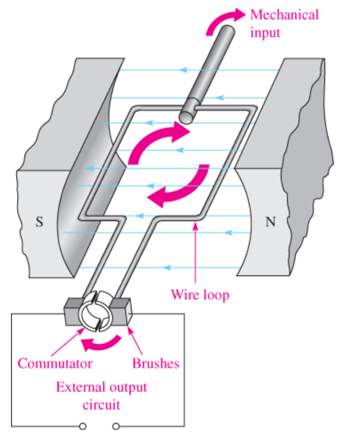
Generator

Structure of a DC Generator

- Similar to an AC generator but uses a **split-ring commutator** or just **commutator** instead of slip rings.
- **Split-Ring Commutator**: A single ring split into two halves, insulated from each other, which reverses the connection of the coil to the external circuit every half-rotation.
- **Note**
  - Other components (magnet, armature, brushes) are similar to the AC generator.



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Generator

How DC generator works

- Like the AC generator, the DC generator uses electromagnetic induction.
- The coil rotates in the magnetic field, inducing an EMF.
- The split-ring commutator reverses the connection of the coil to the external circuit every half-rotation, ensuring the current flows in one direction in the external circuit.
- This results in a **unidirectional (DC)** output.

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AC vs DC Generator

The table below shows the main differences between an AC generator and a DC generator

Feature	AC Generator	DC Generator
Output Current	Alternating (changes direction)	Direct (flows in one direction)
Commutator	Slip rings	Split-ring commutator
Output Waveform	Sinusoidal (AC)	Pulsating DC
Applications	Power grids, household appliances	Battery charging, DC motors

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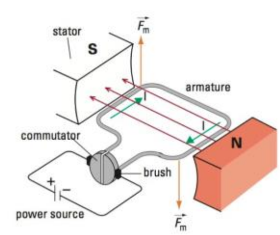
DC Motor

- A **DC motor** is an electrical device that converts electrical energy (direct current) into mechanical energy (rotation).
- It operates on the principle that a current-carrying conductor in a magnetic field experiences a force, known as the **motor effect**.
- Motor effect is when **electric current** flows through a wire in a magnetic field, and the wire is **pushed** (it moves).
- This is because the **magnetic field** interacts with the **electric current** in the wire to produce a **force** that pushed the wire.
- The figure below shows the structure of a DC motor:



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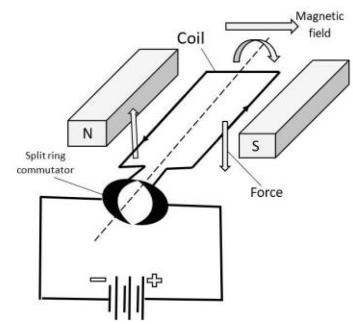
Structure of a DC Motor

- **Permanent Magnets**
  - Create a magnetic field.
- **Armature**
  - A coil of wire wound around an iron core, placed between the poles of the magnet.
- **Carbon Brushes**
  - Maintain electrical contact with the commutator to supply current to the coil.
- **Split-Ring Commutator**
  - A split metal ring connected to the coil, which reverses the current direction in the coil every half-rotation.
- **Power Supply**
  - A DC source (e.g., battery) provides the current.



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DC Motor

How a DC motor works

- When a current flows through the coil, it creates a magnetic field around the coil.
- The coil's magnetic field interacts with the external magnetic field (from the magnets), producing a force on the coil (based on **Fleming's Left-Hand Rule**).
  - **Fleming's Left-Hand Rule**: Hold your left hand with the **First finger (Field)** pointing in the direction of the magnetic field, the **Second finger (Current)** in the direction of the current, and the **Thumb (Motion)** will point in the direction of the force.
- This force causes the coil to rotate.
- As the coil rotates, the split-ring commutator reverses the current direction every half-rotation, ensuring the force always acts in the same rotational direction, allowing continuous rotation.

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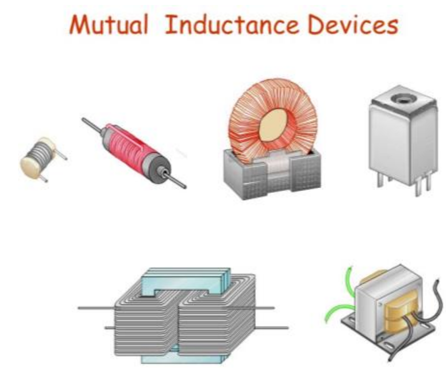
Mutual Induction



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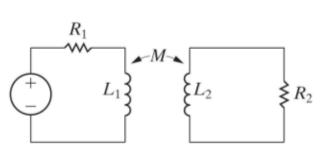
Definition

- **Mutual induction** is the phenomenon where a changing current in one coil induces an EMF in a nearby coil due to a changing magnetic field.
- It is the basis for devices like ***transformers***.

Explaining mutual induction

- Consider the circuit below:



- When two coils are placed close to each other, as a shown in the circuit, a changing current in the **primary coil (L1)** creates a changing magnetic field.
- This changing magnetic field links with the **secondary coil (L2)**, inducing an EMF in the secondary coil (Faraday's Law).
- The magnitude of the induced EMF depends on:
  - The rate of change of current in the primary coil.
  - The number of turns in the secondary coil.
  - The magnetic coupling between the coils.

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Mutual induction example

Effects of soft iron core on induced EMF

- A **soft iron core** is often placed inside or between the coils to enhance mutual induction.
- The soft iron core affect the induced EMF by:
  - Increasing the magnetic flux.
  - Improves flux linkage.
  - Reduces flux linkage.
  - Improves efficiency.

- **For example:**
  - In a transformer, when the primary and secondary coils are wound around a soft iron core.
  - The current in the primary coil changes, the core amplifies the magnetic flux, inducing a larger EMF in the secondary coil compared to an air-core setup.

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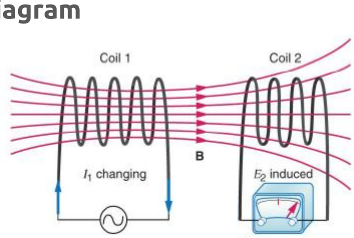
Mutual induction experiment

Materials

- Two thin copper coiled wires
- AC power supply
- Galvanometer

Diagram



Steps

- Connect the ends of the two coils to an AC supply and the other to a galvanometer respectively so that you have two circuits as shown in the diagram.
- Bring the coils close to each other.
- Observe the galvanometer needle.

Observation

- The galvanometer pointer/ needle get deflected.

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Mutual induction experiment

Explanation

- The pointer on the galvanometer gets deflected because the EMF is induced in the coil connected to the galvanometer.
- When alternating current flows through the primary coil, alternating magnetic field is produced. This alternating magnetic field cuts the secondary coil.
- The cutting of alternating magnetic field on the secondary coil induces EMF in the secondary coil, which causes deflection on the pointer of a galvanometer.
- This type of induction is called **mutual inductance**.

Questions

1. Explain why a DC generator uses a split ring commutator instead of a slip ring.
2. Draw a labelled diagram of an AC generator and explain how it works.
3. Describe an experiment that can be carried out to demonstrate mutual induction.

Next: Transformers