SESSION 10: ELECTROMAGNETISM

Key Concepts

- Magnetic field around a straight current carrying conductor
- Magnetic field around a single loop (simple coil)
- Magnetic field around a solenoid (coil with many turns)
- Electromagnetic Induction
- Electromagnetic Induction by electrical methods
- Charged particles in a magnetic field

X-planation

1. INTRODUCTION

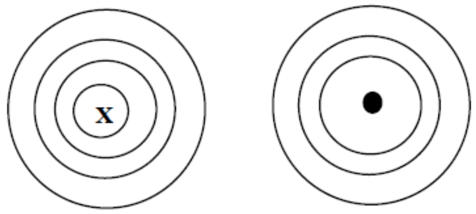
- **Electromagnetism:** the study of the properties of and relationship between electric currents and magnetic fields.
- **Electric current:** rate of flow of charge, formula: **I = Q/t**
- The charge carriers – in **metals** it is **electrons**, in **electrolytes** it is **negative and positive charges**.
- 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**.

1.1. MAGNETIC FIELD AROUND A CURRENT-CARRYING STRAIGHT CONDUCTOR

- The magnetic field lines caused by the electric current 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:**

  If you grasp the conductor with your right hand, with your thumb pointing in the direction of the electric current, the curled fingers represent the direction of the magnetic field.

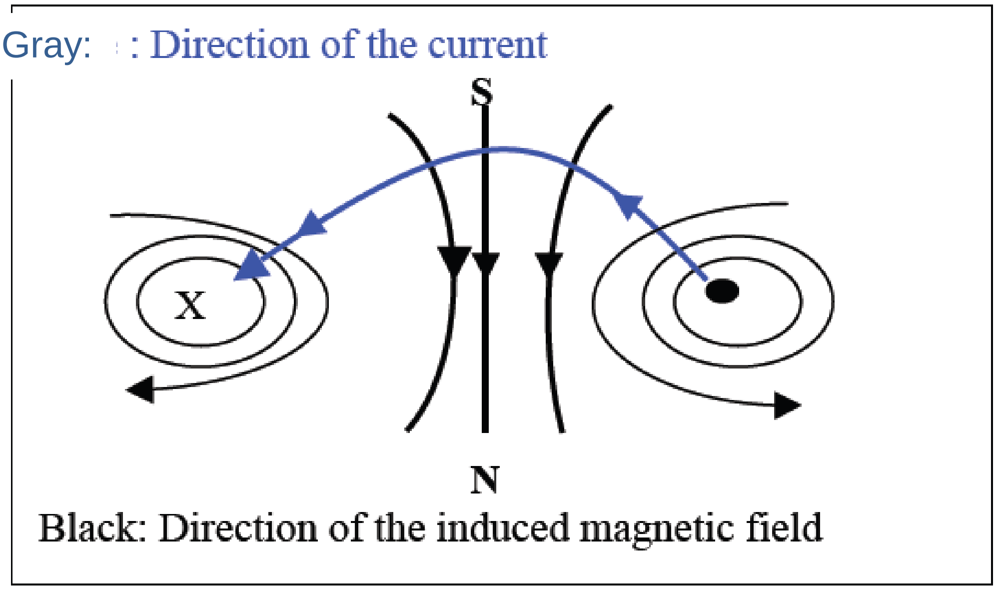
Diagrammatic representation



X – away from the observer
● - towards the observer

1.2. THE MAGNETIC FIELD AROUND A CURRENT-CARRYING COIL

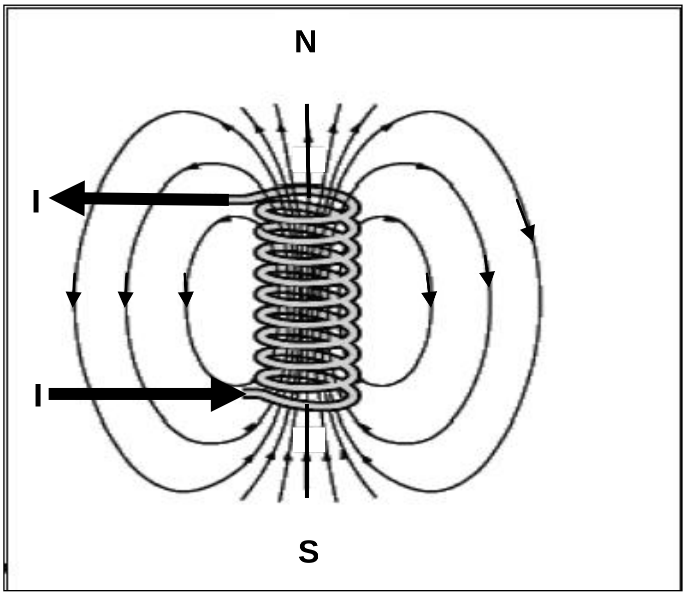
- When a current-carrying conductor is bent into a single loop, the magnetic field around it forms the pattern shown below:



- The pattern shows that the magnetic field is like that of a flat, disc-shaped magnet with N-pole on one face and S-pole on the other side.
- The magnetic field inside the circle is stronger than outside as it is an interaction of the induced magnetic fields of the ends of the conductor going in the same direction.
- Near the centre of the circle the magnetic field is fairly uniform (field lines parallel).
- The direction of the field lines can be determined with the help of the right hand rule.
- The field lines form closed loops around the conductor and inside the coil the direction is, therefore, S to N, and this is opposite to the direction outside the loop.

1.3. THE MAGNETIC FIELD AROUND A CURRENT-CARRYING SOLENOID

- A solenoid is a large number of insulated turns forming a cylindrical coil.
- The magnetic field pattern around a solenoid is shown below:



A current-carrying solenoid is surrounded by a magnetic field which is similar to the magnetic field around a bar magnet. I is current direction.

There is also a magnetic field inside the solenoid, pointing from S to N.

The Right Hand Solenoid Rule can be used to determine the polarity of the solenoid.

Place your right hand around the solenoid with your thumb outstretched and your curled fingers pointing in the direction of the current, then your thumb points in the direction of the N-pole of the solenoid.

1.4. ELECTROMAGNETS AND MAGNETIC MATERIALS

- An electromagnet is a conductor which becomes magnetic when there is current flowing through it.
- Not all substances can be magnetised easily nor do all substances lose their magnetism equally easily.
- Some substances, like iron, are **easily magnetised and demagnetised** and these are referred to as **soft magnetic materials**.
- Other substances, like steel, are **more difficult to magnetise but retain the magnetism longer** and these are referred as **hard magnetic materials**.
- The strength of electromagnets depends on:
    - The current in the conductor (coil)
    - The number of turns around the core
    - The type of substance used in the core

1.5. USES OF ELECTROMAGNETS

- Electromagnets come in a variety of sizes, shapes and strengths and are used in a large variety of appliances.
- Some of the uses include:
  - Lifting magnets
  - Electric bells
  - Relays
  - Loud speakers
  - Telephone receivers
  - Tape & video recorders
  - Electric motors

2. ELECTROMAGNETIC INDUCTION

2.1 Faraday's Law

- If a magnet is moved relative to a coil, an electric current is induced in the circuit by a process of **electromagnetic induction**; in fact an emf is reduced which causes a flow of current in a closed circuit.
- The induced current flows only while the magnetic field moves relative to the solenoid, i.e. when there is a change in the magnetic flux linkage with the solenoid. Its direction keeps changing; hence it is called alternating current, AC.
- The strength of the induced current increases when:
  - the speed of movement of magnet relative to the coil increases
  - the magnetic flux linkage is increased (i.e. a stronger magnet)
  - the number of turns on the solenoid increases
- The magnetic flux linkage, Φ, is given by

  $$\Phi = BA$$

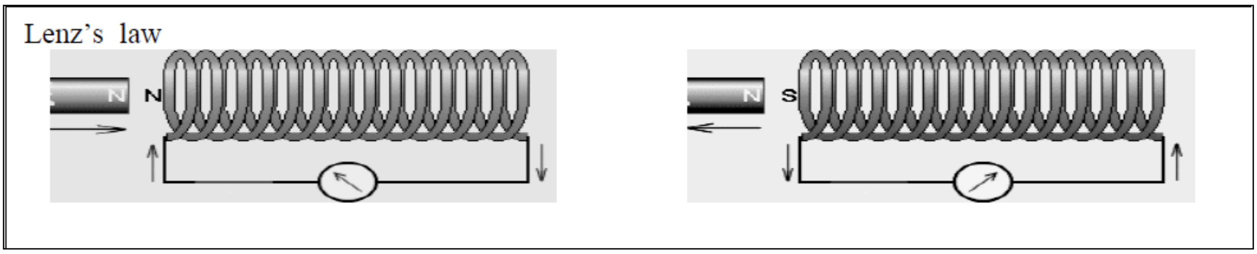
  where **B is the magnetic field strength over an area A**.
- Any change in magnetic flux, Φ, induces an emf, and this process is defined as electromagnetic induction.

- **Faraday's Law of Electromagnetic Induction states that the induced emf, Є, is directly proportional to the change in flux ΔΦ and inversely proportional to Δt.**
- If a coil has N turns, an emf will be produced that is N times greater than for a single coil so that Φ is directly proportional to N.
- The equation for the emf induced is

$$\varepsilon = -N.\frac{\Delta \Phi}{\Delta t}$$

2.2 THE DIRECTION OF THE INDUCED CURRENT: LENZ'S LAW

- **Lenz's Law states that the direction of the induced current is such that the magnetic field it established tends to oppose the cause of the induction**.



- If a N-pole approached the coil, a N-pole is induced in the coil in order to oppose the approaching magnet, and using the Right Hand Solenoid rule the direction of the current can be determined.
- If the N-pole is withdrawn, the top end of the coil becomes an S-pole in order to attract the N-pole of the magnet.

3. ELECTROMAGNETIC INDUCTION BY ELECTRICAL METHODS

3.1. MUTUAL INDUCTION

- When current is available (DC from a battery or AC from a dynamo), a changing current can be used to provide a changing magnetic field which is necessary for inducing another current in a second conductor.
- **The phenomenon that occurs when an emf (and, therefore, a current) is induced in a coil by means of the changing magnetic field caused by current changes in a neighbouring coil, is called mutual induction.**
- The coil in which there was a deliberate change in the current and magnetic field, is called the primary coil, and the coil in which there was an induced current, is called the secondary coil.
- The induced potential difference in the secondary coil can be made higher or lower than the potential that is applied in the primary coil, depending on the number of turns on the coils. This is the **principle of a transformer**.

3.2 THE PRINCIPLE OF AN AC TRANSFORMER (NOT EXAMINABLE)

- If the number of turns in the primary and secondary coil is equal, the voltage across the secondary equals the voltage across the primary coil.
- If the number of turns in the secondary coil is greater than in the primary coil, the voltage across the secondary is greater than the voltage in the primary coil. This is called a **step-up transformer** as it steps the voltage up to a higher level.
- If the number of turns in the secondary coil is less than the number in the primary coil, then the voltage across the secondary coil is less than the voltage in the primary. This is a **step-up** transformer as it steps the voltage down to a lower level.
- Step-up transformers are used in televisions. They transform the 240V a.c. mains voltage to about 25 000V.
- Step-down transformers are used in cell phone chargers. They transform the 240V AC mains to 9V. However, the cell phone charger requires direct current, so the AC has to be rectified to DC.
- The size of the induced voltage depends on the number of turns in the two coils.

$$\frac{\text{Voltage in primary}}{\text{Voltage in secondary}} = \frac{\text{turns in primary}}{\text{turns in secondary}}$$

In symbols: $\frac{V_p}{V_s} = \frac{N_p}{N_s}$

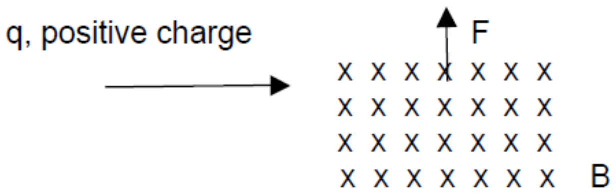
- In any perfect transformer:

  Energy supplied to the primary = energy drawn from the secondary.

4. CHARGED PARTICLES IN MAGNETIC FIELDS (NOT EXAMINABLE)

Any charged particle that is moving has the same effect as an electric current. Thus when these charged particles that are moving enter a magnetic field, they will experience a force. The maximum force exerted will be at right angles to the velocity of the charge and at right angles to the direction of the magnetic field. The magnitude of the force is given by:

$F = qvB$ where q is the charge in Coulmb (C)
v is the velocity of the charge ($m \cdot s^{-1}$)
B is the magnetic field in Tesla (T)



Point the fingers of your right hand in the direction of the magnetic field B, your thumb in the direction of the velocity of the positive charge,v, and then your palm points in the direction of the magnetic force F on the charge.

X-ample Questions

Question 1

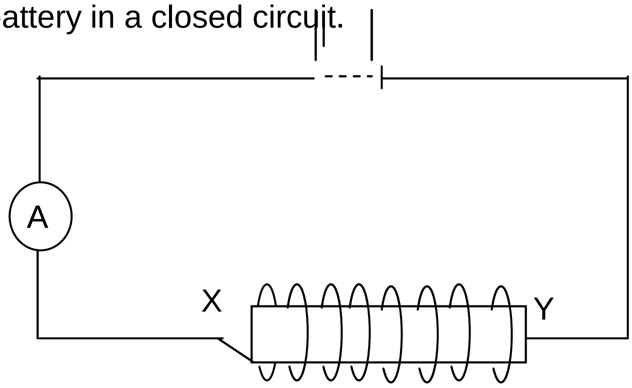
A piece of copper wire is clamped into a vertical position. When connected to a battery in a closed circuit, the direction of current is downwards. Draw a sketch to show the current and magnetic field when viewed from:

1.1 above the conductor. (4)

1.2 the side. (4)

Question 2

The sketch below shows a circular coil wrapped around a plastic pipe. The coil is connected to battery in a closed circuit.



2.1 Draw a sketch of the coil when viewed from above. Show the direction of the current and the magnetic field clearly (4)

2.2 Draw a sketch of the coil when viewed looking into the coil at the end labelled X. Show the direction of the current and the magnetic field clearly. (4)

2.3 The coil has a radius of 3 cm. The magnetic field produced by the electromagnet is 2,5 T. Calculate the magnetic flux, Φ, inside the coil. (5)

2.4 Name two ways in which the electromagnet can be made stronger. (2)

Question 3

You are given a coil, connecting wires, a bar magnetic and a galvanometer. Describe how you would use this apparatus to verify Lenz's Law.

(8)

Question 4

A circular coil of wire of radius 2 cm and which has 80 turns, is connected to a galvanometer in a closed circuit. A magnet creating a magnetic field of 50mT is pulled quickly from inside the coil until it is far enough away from the coil so that the field inside the coil is zero. The time it takes for the magnetic to move is 0,2s. Calculate the reading on the galvanometer.

(5)

Question 5

A transformer has 600 turns in the primary coil and 30 turns in the secondary coil.

5.1. What type of transformer is this?

(2)

5.2. If 220V is applied to the primary coil, what voltage will be provided by the secondary coil?

(3)

Question 6

A transformer with negligible power loss is connected to a 120V input. The primary coil has 600 turns and the secondary coil has 15 000 turns. The secondary coil is connected to an external circuit which has a resistance of $2,8 \times 10^5\ \Omega$.

6.1 Calculate the potential difference the secondary coil supplies to the circuit. (3)

6.2 Calculate the current in the external circuit. (3)

6.3 What is the power supplied by the transformer to the external circuit?

(3)

Question 7

An electron moves horizontally at a speed of 200 $m.s^{-1}$ into a magnetic field of 0,5T that lies perpendicular to the motion of the electron.

7.1 Describe the motion of the electron on entering the magnetic field (3)

7.2 Calculate the force exerted on the electron (4)

X-ercises

1. As an observer looks at it, an electric current in a coil flows clockwise. The direction of the magnetic field is

   A. to the left.
   B. to the right.
   C. towards the observer.
   D. away from the observer.

2. In order to achieve unlike magnetic poles at the ends of a horseshoe electromagnet, the coils around the limbs of the magnet must

   A. both carry current in clockwise circular directions.
   B. both carry current in anti-clockwise circular directions.
   C. carry the current in at the one coil and out at the other.
   D. carry the current clockwise in one coil and anti-clockwise in the other.

3. The force between a magnetic field and an electric current is the strongest when the current flows

   A. at right angles to the magnetic field.
   B. from N to S in the magnetic field.
   C. from S to N in the magnetic field.
   D. in a solenoid with the magnetic field inside it.

4. To obtain current in a coil by means of electromagnetic induction, one needs

   A. a coil and a magnet.
   B. a coil, a magnet and a battery.
   C. a coil, a galvanometer and a magnet.
   D. a coil and a galvanometer.

5. A coil is situated in the magnetic field of a magnet. Current will be induced in the coil

   A. only when the magnet is moved.
   B. only when the coil is moved.
   C. if the coil and magnet are moved together.
   D. if either the coil or the magnet is moved.

6. Current flowing in a primary coil can induce current in a secondary coil

   A. only when the current increases.
   B. only when the current decreases.
   C. only when the direction of the current is reversed.
   D. as soon as there is any change at all in the current.

7. When a soft iron is placed in a current-carrying conductor, it

   A. reverses the current.
   B. increases the current.
   C. decreases the current.
   D. increases the magnetic field.

8. Two coils are placed next to each other. The one coil is connected to a battery and an open switch, the other is connected to a galvanometer. When the switch S is closed, the needle of the galvanometer moves to the right. If S is kept closed, the galvanometer needle will

   A. return to zero.
   B. stay pointing to the right.
   C. move over to the left.
   D. move to and fro until the switch is opened.