UNIT 2: ELECTRICITY AND MAGNETISM, A. C. THEORY AND ELECTRONICS, ATOMIC AND NUCLEAR PHYSICS

MODULE 1: ELECTRICITY AND MAGNETISM

GENERAL OBJECTIVES

On completion of this Module, students should:

1. understand electrostatic phenomena;
2. understand electrical quantities and the relationships among them;
3. analyse circuits with various electrical components;
4. understand the concept of electric fields;
5. be aware of the design and use of capacitors;
6. demonstrate a conceptual understanding of magnetic fields;
7. understand how magnetic forces arise;
8. demonstrate a working knowledge of electromagnetic phenomena.

SPECIFIC OBJECTIVES

1. Electrical Quantities

Students should be able to:

1.1 use the equation \( Q = It \) to solve problems;
1.2 define the ‘coulomb’;
1.3 define the ‘volt’;
1.4 use the equation \( V = \frac{W}{Q} \) to solve problems;
1.5 use the equation \( V = IR \) to solve problems;

EXPLANATORY NOTES

Students should be able to:

1.1 use the equation \( Q = It \) to solve problems;
1.2 define the ‘coulomb’;
1.3 define the ‘volt’;
1.4 use the equation \( V = \frac{W}{Q} \) to solve problems;
1.5 use the equation \( V = IR \) to solve problems;
UNIT 2
MODULE 1: ELECTRICITY AND MAGNETISM (cont’d)

SPECIFIC OBJECTIVES

Electrical Quantities (cont’d)

1.6 use the equations $P = IV$, $P = I^2R$, $P = V^2/R$ to solve problems;

1.7 define and use the term resistivity;

1.8 use energy considerations to distinguish between e.m.f. and p.d.;

1.9 explain drift velocity ($\nu$);

1.10 derive and use the equation $I = ne\nu A$ for electrons moving in a metal($n =$ charge density).

EXPLANATORY NOTES

$R = \frac{\rho L}{A}$

Include the observation that e.m.f is associated with sources or active devices whereas p.d. is used in reference to an electric field or passive device.

Since a similar equation describes the flow of particles in uniform channels, candidates should be able to apply such equations to semiconductors and electrolytes.

2. Electrical Circuits

Students should be able to:

2.1 sketch the $I$ - $V$ characteristic for a metallic conductor at constant temperature, a semiconductor diode, and a filament lamp;

2.2 sketch the variation of resistance with temperature for a thermistor with negative temperature co-efficient;

2.3 solve problems involving terminal p.d. and external load, given that sources of e.m.f. possess internal resistance;

2.4 draw and interpret circuit diagrams;

Explain these characteristics in terms of the variation in resistance of the device.

Also include different types of thermistors and discuss the differences between the R – T characteristics.

Use examples of different types of source, for example, primary and secondary chemical cells, solar cells, generators.

Consider d.c. circuits involving sources of e.m.f and resistive circuit elements.
UNIT 2
MODULE 1: ELECTRICITY AND MAGNETISM (cont’d)

SPECIFIC OBJECTIVES

Electrical Circuits (cont’d)

Students should be able to:

2.5 apply Kirchhoff’s laws to given circuits;  
Kirchhoff’s First Law is a consequence of conservation of charge and Kirchhoff’s Second Law, a consequence of conservation of energy.

2.6 derive and use the formula for the effective resistance of two or more resistors in series;

2.7 derive and use the formula for two or more resistors in parallel;

2.8 use the potential divider as a source of variable and fixed p.d.;

2.9 use the Wheatstone bridge as a means of comparing resistances.  
Treat as a double potential divider.

3. Electric Fields

Students should be able to:

3.1 explain the difference between electrical conductors and insulators;  
An electron model should be used in the explanation.

3.2 discuss simple practical applications of electrostatic phenomena, such as agricultural spraying and dust extraction;  
Additional examples can be drawn from more modern devices such as electrostatic copiers and laser printers.

3.3 discuss hazards associated with charging by friction;  
Mention the magnitudes of the physical quantities involved.

3.4 explain the action of lightning rods in the protection of buildings;  
Requires only a simple explanation of how a gas breaks down and begins to conduct when subjected to very high electric fields.
UNIT 2
MODULE 1: ELECTRICITY AND MAGNETISM (cont’d)

SPECIFIC OBJECTIVES

Electric Fields (cont’d)

Students should be able to:

3.5 use Coulomb’s Law for the force between charges in free space or air to solve problems;

3.6 use \( E = \frac{Q}{4\pi \varepsilon_0 r^2} \) for the field strength due to a point charge;

3.7 calculate the field strength of the uniform field between charged parallel plates, in terms of potential difference and separation of the plates;

3.8 calculate the force on a charged particle in a uniform electric field;

3.9 describe the effect of a uniform electric field on the motion of charged particles;

3.10 solve numerical problems involving the motion of charged particles in a uniform electric field and compare this motion to that of a projectile in a gravitational field;

3.11 use the fact that the field strength at a point is numerically equal to the potential gradient at that point;

3.12 use the equation \( V = \frac{Q}{4\pi \varepsilon_0 r} \) for the potential due to a point charge;

EXPLANATORY NOTES

Consider combinations of charges arranged in very simple arrangements. Use a vector approach to determine the resultant force on a single point charge due to other point charges.

\( E \) is a vector.

\( E = \frac{V}{d} \)

\( F = EQ \)

Consider motions perpendicular and parallel to the electric field.

Consider the uniform electric field and by determining the work done per unit charge, verify this relationship. Refer to Specific Objective 3.7

Compare the potential due to a point charge with that due to a charged sphere of radius \( r \).

\( V \) is a scalar.
UNIT 2
MODULE 1: ELECTRICITY AND MAGNETISM (cont’d)

SPECIFIC OBJECTIVES

Electric Fields (cont’d)

Students should be able to:

3.13 find the potential at a point due to several charges.

4. **Capacitors**

Students should be able to:

4.1 explain the ‘farad’;

4.2 use \( C = \frac{Q}{V} \) to solve problems;

4.3 use the formula \( C = \frac{\varepsilon A}{d} \);

4.4 derive and use formulae for capacitors in parallel and series to solve problems;

4.5 use the energy stored in a capacitor as \( W = \frac{CV^2}{2} \), \( W = \frac{QV}{2} \) and \( W = \frac{Q^2}{2C} \) to solve problems;

4.6 recall and use the equations for capacitor discharge:

\[
Q = Q_0 \exp \left( \frac{-t}{RC} \right)
\]

\[
I = I_0 \exp \left( \frac{-t}{RC} \right)
\]

\[
V = V_0 \exp \left( \frac{-t}{RC} \right)
\]

(RC is the “time constant” and measured in seconds.)

EXPLANATORY NOTES

Contrast with vector addition in Specific Objectives 3.5 and 3.6.

Refer to the use of dielectrics to produce capacitors of larger values with the same dimensions. Mention the types of dielectrics and the range of their dielectric constants or relative permittivity.

Include problems on equivalent capacitance for simple series parallel combinations.

Discuss the mechanism of energy storage in a capacitor.
UNIT 2
MODULE 1: ELECTRICITY AND MAGNETISM (cont’d)

SPECIFIC OBJECTIVES

Capacitors (cont’d)

Students should be able to:

4.7 sketch graphs illustrating the charge and discharge of a capacitor.

5. Magnetic Fields

Students should be able to:

5.1 explain ‘magnetic flux density’ and the ‘tesla’;

5.2 sketch magnetic flux patterns due to a long straight wire, a flat circular coil and a long solenoid;

5.3 use the expressions for the magnetic flux density of a distance \( r \) from a long straight wire, the centre of a flat circular coil and near the centre of a long solenoid, respectively.

6. Magnetic Forces

Students should be able to:

6.1 use Fleming’s Left-Hand Rule to predict the direction of the force on a current-carrying conductor;

6.2 use the equation \( F = BIL \sin \theta \) to solve problems;

6.3 explain how the force on a current-carrying conductor can be used to measure the flux density of a magnetic field by means of a current balance;

EXPLANATORY NOTES

Q, V or I against t.

\[ B = \frac{\mu_0 I}{2\pi r} \quad B = \frac{\mu_L}{2\pi} N I \quad \mathbf{B} = \mu_0 n \mathbf{I} \]

See suggested practical activities on page 44.

See suggested practical activity on page 45.
UNIT 2
MODULE 1: ELECTRICITY AND MAGNETISM (cont’d)

SPECIFIC OBJECTIVES

Magnetic Forces (cont’d)

Students should be able to:

6.4 predict the direction of the force on a charge moving in a magnetic field;

6.5 use the expression \( F = BQ \sin \theta \) to solve problems;

6.6 solve problems involving charged particles moving in mutually perpendicular electric and magnetic fields;

6.7 describe the effect of a soft iron core on the magnetic field due to a solenoid;

6.8 explain the principle of the electromagnet and discuss its uses in doorlocks, switches and other applications;

6.9 explain the origin of the forces between current-carrying conductors, and predict the direction of the forces;

6.10 explain the Hall effect;

6.11 use the Hall probe to measure flux density.

EXPLANATORY NOTES

Use Fleming’s Left-Hand Rule and treat the moving charge as an electric current.

Qualitative discussion of the trapping of charged particles by magnetic fields with specific mention of earth’s magnetic field and the Van Allen radiation belt.

Compare this effect with that of the dielectric in a capacitor.

In developing the explanation, refer to Specific Objective 6.5
### UNIT 2  
MODULE 1: ELECTRICITY AND MAGNETISM (cont’d)

#### SPECIFIC OBJECTIVES

<table>
<thead>
<tr>
<th>Objectives</th>
<th>EXPLANATORY NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Electromagnetic Induction</td>
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<tr>
<td>Students should be able to:</td>
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<tr>
<td>7.1 explain magnetic flux and use the equation ( \Phi = BA ) to solve problems;</td>
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<tr>
<td>7.2 explain the ‘weber’;</td>
<td>Explain separately and qualitatively the effects obtained when:</td>
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<tr>
<td>7.3 describe and interpret experiments which demonstrate the relationship between the magnitude and direction of an induced e.m.f. and the change of flux linkage producing the e.m.f.;</td>
<td>(a) bar magnet moves inside a solenoid; (b) two flat coils move with respect to each other; (c) bar magnet moves with respect to flat coil; (d) one solenoid moves inside another; (e) solenoid moves inside a flat coil.</td>
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<tr>
<td>7.4 use Faraday’s Law of electromagnetic induction to determine the magnitude of an induced e.m.f.;</td>
<td>In your explanation, refer to Specific Objective 7.5.</td>
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<tr>
<td>7.5 use Lenz’s Law to determine the direction of an induced e.m.f.;</td>
<td>See suggested practical activity on page 46.</td>
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<tr>
<td>7.6 discuss Lenz’s Law as an example of conservation of energy;</td>
<td>Include ( E = BLv ) for a straight conductor.</td>
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<tr>
<td>7.7 explain simple applications of electromagnetic induction;</td>
<td>Transformers, ac and dc motors and generators should be discussed as major applications of electromagnetic induction.</td>
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<tr>
<td>7.8 explain the principle of operation of the simple transformer;</td>
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UNIT 2
MODULE 1: ELECTRICITY AND MAGNETISM (cont’d)

SPECIFIC OBJECTIVES

Electromagnetic Induction (cont’d)

Students should be able to:

7.9 Use the relationship \( \frac{N}{N'}I_s = \frac{V_s}{V_p} = \frac{I_p}{I_s} \) for the
ideal transformer.

Suggested Teaching and Learning Activities

To facilitate students’ attainment of the objectives of this Module, teachers are advised to engage students in Practical Activities outlined below.

PRACTICAL ACTIVITIES

The teacher is urged to reinforce the relevant approved codes and safety practices during the delivery of all practical activities in the Module.

THE MAGNETIC FIELD OF A SOLENOID

Refer to Specific Objective 5.3

Aim: To investigate the factors affecting the magnetic flux density of a solenoid.

This experiment uses a Hall probe and a direct current flowing in the solenoid. The reading on the voltmeter connected to the probe is directly proportional to B. Sometimes, the meter is already calibrated in mT but usually a conversion factor is used.

Method: (a) Two of the solenoids provided have the same area and length but a different number of turns (which is marked on them). Ensuring that the currents are the same in each by connecting them in series, investigate how B at the centre of the solenoid depends on n, the turn concentration, for at least three different current values.

Also move the probe from side to see how the field varies across the solenoid.

(b) Choose a pair of solenoids with the same number of turns per unit length, n, but different areas and investigate how B depends on the area of cross-section when the other factors are kept constant. Repeat with different currents.

(c) Investigate how the field at the centre of a solenoid depends on the current flowing in it.

Find B at various positions along the solenoid axis and plot a graph to display your results.
UNIT 2
MODULE 1: ELECTRICITY AND MAGNETISM (cont’d)

FORCE ON CURRENT-CARRYING CONDUCTOR

Refer to Specific Objective 6.3

Aim: To test the relationship $F=\text{BIL}$ for the force on a current-carrying conductor.

Method: Set up the apparatus shown above so that an upward force will be exerted on the wire when the current is flowing. Before switching on, press the tare bar on the balance to set the reading at zero.

Since the conductor is forced upward, an equal and opposite force will push the magnet down (Newton III) so the force on the wire may be calculated from the balance reading.

According to the texts, the force on a current-carrying wire AT RIGHT ANGLES to a uniform field is:

(a) proportional to the current, $I$, flowing in the conductor;

(b) proportional to the length, $L$, of the conductor.

Use this apparatus to test these two statements.

Also use both sets of data to find the proportionally constant $B$ (known as the flux density of the uniform field) in the relationship, $F=\text{BIL}$.
UNIT 2
MODULE 1: ELECTRICITY AND MAGNETISM (cont’d)

THE LAWS OF ELECTROMAGNETIC INDUCTION

Refer to Specific Objective 7.4

Aim: To test the Faraday relationship: induced e.m.f. equals the rate of change of magnetic flux linkage.

\[ E = NA \frac{dB}{dt} \]

Theory

Flux linkage = NAB where N is the number of turns in the secondary coil, A is the area of the coil and B is the magnetic flux density produced by the primary coil.

To investigate the relationship above, two of the quantities must remain constant while the third is varied. (Note that the rate of change of B depends on the rate of change of I which is proportional to the frequency).

Apparatus: Pair of solenoids of square cross-section; one has twice the area of the other.

Signal generator: use the low impedance output and set the frequency on the 100 to 1000 Hz range.

Cathode ray oscilloscope for measuring the peak induced voltage.

A.C. ammeter to ensure that the current is constant (so that B is constant).

Long length of insulated copper wire to wind various numbers of turns on the solenoids.