TOPIC 22 Electromagnetic Induction

Objectives

Candidates should be able to:

(a) deduce from Faraday's experiments on electromagnetic induction or other appropriate experiments:
  (i) that a changing magnetic field can induce an e.m.f. in a circuit
  (ii) that the direction of the induced e.m.f. opposes the change producing it
  (iii) the factors affecting the magnitude of the induced e.m.f.

(b) describe a simple form of a.c. generator (rotating coil or rotating magnet) and the use of slip rings (where needed)

(c) sketch a graph of voltage output against time for a simple a.c. generator

(d) describe the use of a cathode-ray oscilloscope (c.r.o.) to display waveforms and to measure potential differences and short intervals of time (detailed circuits, structure and operation of the c.r.o. are not required)

(e) interpret c.r.o. displays of waveforms, potential differences and time intervals to solve related problems

(f) describe the structure and principle of operation of a simple iron-cored transformer as used for voltage transformations

(g) recall and apply the equations $V_P / V_S = N_P / N_S$ and $V_P I_P = V_S I_S$ to new situations or to solve related problems (for an ideal transformer)

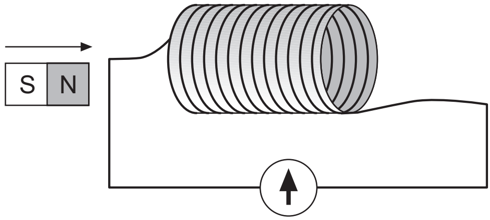
(h) describe the energy loss in cables and deduce the advantages of high voltage transmission

NOTES

22.1 Principles of Electromagnetic Induction

1. Electromagnetic induction: When there is a change in the magnetic flux (magnetic field) linking the conductor, an e.m.f. and hence a current is induced between the ends of the conductor.

2. When the North pole of the bar magnet is moved towards the solenoid, an induced current is generated which produces a North pole at the end of the solenoid facing the magnet. The induced North pole is to oppose the motion of the magnet's North pole. Once the magnet stops moving, the induced current dies down to zero.



3. Faraday's Law of electromagnetic induction:
   The magnitude of the induced e.m.f. is directly proportional to the rate of change of magnetic flux linking the coil.

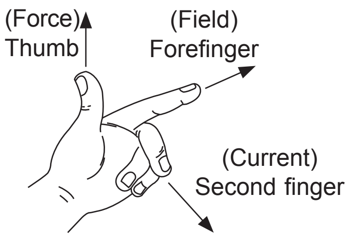
4. A larger e.m.f. is produced when:
   (a) the number of turns of wire in solenoid is increased.
   (b) a stronger magnet is used.
   (c) the speed with which magnet is moved towards or away of the solenoid is increased.
   (d) a soft iron core is placed inside the solenoid.

5. Lenz's Law: The direction of induced current sets up a magnetic field to oppose the change in the magnetic flux producing it.

6. Fleming's left hand rule and Fleming's right hand rule

<table>
<tr><th>Left Hand</th><th>Right Hand</th></tr>
<tr>
<td>
Quantities involved:
• Direction of force on conductor
• Direction of current
• Direction of magnetic field.

Given directions of any two of the above three quantities, it is possible to find the direction of the third quantity.



Thumb: Direction of force
Forefinger: Direction of field
Second Finger: Direction of current in wire
Note: The three fingers must be held at 90° to each other.
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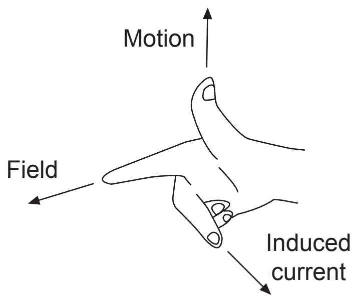
Quantities involved:
• Direction of induced current
• Direction of magnetic field
• Direction of motion

Given directions of any two of the above three quantities, it is possible to find the direction of the third quantity.



Thumb: Direction of motion
First Finger: Direction of field
Second Finger: Direction of induced current in wire
Note: The three fingers must be held at 90° to each other.
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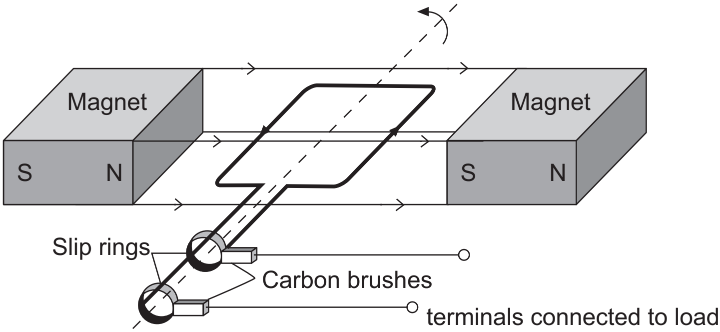
7. Energy Conversion Process

Dynamo, Generator	Kinetic Energy to Electrical Energy
Motor	Electrical Energy to Kinetic Energy

22.2 A.C. Generator

1. 

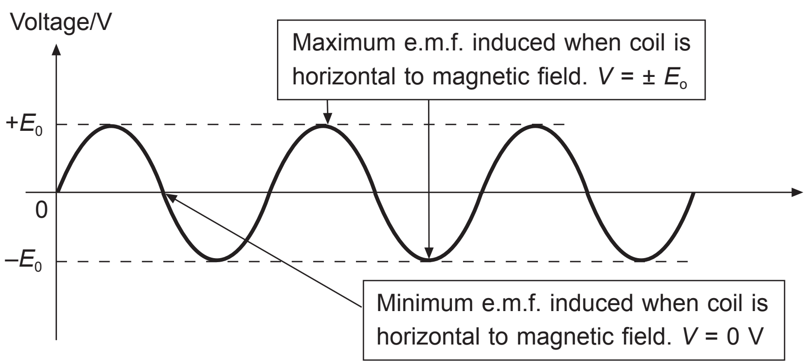
2. An a.c. generator is used to generate electricity. It consists of a coil of rectangular wires situated between two magnets as shown above.

3. When the coil is rotated, it cuts the magnetic field and causes a change in the magnetic flux linkage. As long as the coil keeps on rotating, the rate of change of magnetic flux linking the coil is non-zero and hence, an e.m.f. will be induced in the coil. By Faraday's Law of electromagnetic induction, the magnitude of the e.m.f. that is induced in the coil is directly proportional to the rate of change of magnetic flux linking the coil.

4. Kinetic energy (rotation) is converted into electrical energy.

5. The a.c. generator's coil is connected to two slip-rings which make sliding contact with the carbon brushes at all times (unlike the split-ring commutator used by d.c. motors).

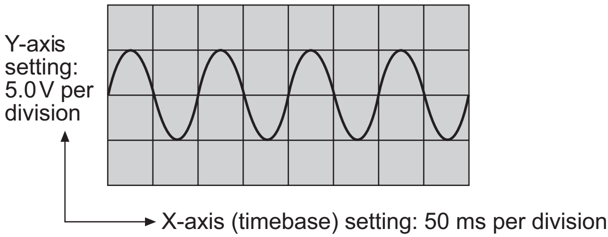
6. The voltage-time graph of the induced e.m.f. is as follows:



22.3 Uses of Cathode-Ray Oscilloscope (c.r.o.)

1. Measure p.d.
2. Display waveforms
3. Measure short time intervals

Example 22.1



Amplitude = one division = 5.0 V

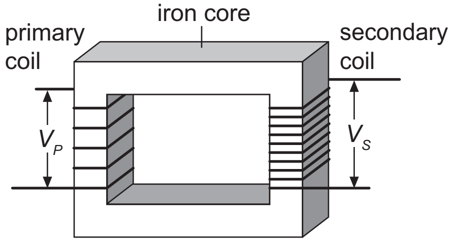
Period, T = 2 divisions = 100 ms = 0.1 s

Frequency, $f = \frac{1}{T} = \frac{1}{0.1} = 10$ Hz

22.4 Principles of Operation of a Transformer

1. The advantage of producing a.c. instead of d.c. at power plants is that a.c. can be stepped up or down to suit household and industries' needs. Household a.c. voltage is stepped down to 240 V.

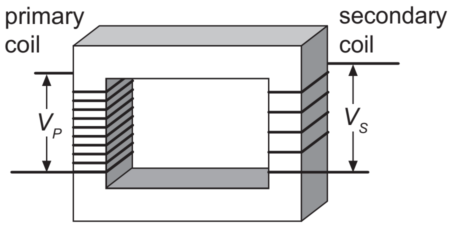
2. The following diagram shows a step-up and a step-down transformer:



Step-up transformer

$V_P < V_S$

$N_P < N_S$



Step-down transformer

$V_P > V_S$

$N_P > N_S$

3. Principle of operation of a transformer:
   a.c. will produce a changing magnetic field. By coiling a primary coil of wires and a secondary coil around an iron core, the changing magnetic field produced by the primary coil will induce an e.m.f. in the secondary coil.

4. For an ideal transformer, we have:
$P_P = P_S \Rightarrow I_P V_P = I_S V_S$

$$\boxed{\frac{I_P}{I_S} = \frac{N_S}{N_P}}$$

Also, $$\boxed{\frac{V_S}{V_P} = \frac{N_S}{N_P}}$$

Note:
1. For practical transformers, if the load on the secondary circuit increases in resistance (more devices connected to the secondary terminals in series), then the amount of power output required will also increase.
2. The power input ($P = I_P V_P$) from the generator is NOT FIXED. Only V_P and V_S are fixed.
   For N2013/P1/Q40, the 230 V has been transmitted over a long distance <u>without transformers</u>.
3. The amount of I_p depends on consumption.

5. Power plants transmit electricity through thick cables at high voltages for the following reasons:
   (a) A higher voltage will mean a lower current travelling in the cable.
   (b) Thick cables (large cross-sectional area) mean the cables have low resistance.

   $$\left(R = \frac{\rho l}{A}\right)$$

   In this way, less power is lost as heat due to heating effect in the cables.