EXAM PAPERS PRACTICE

Chapter 21

Electromagnetic Induction

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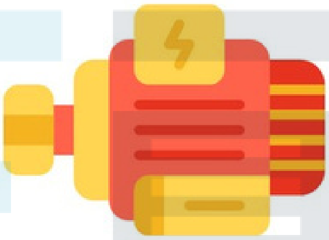
21.1 Generating Electricity

1. From chapter 20, we learned that a motor transfers energy by an electric current into mechanical energy (movement).
2. An electrical generator reverses the process by converting mechanical energy into electric energy.
3. Different types of generators:
   a. Dynamo – An electrical generator used in bicycle for powering the light



   b. Power Station generator

How does it work?

i. The turbines are driven to spin by the high-pressure steam from the boiler.
ii. The generator shares the same axle as the turbine, causing it to spin as well.
iii. Inside the generator, a coil rotates within fixed electromagnets, generating a magnetic field.
iv. As a result, a large current is induced in the rotating coil, which is the current supplied by the power station to consumers.

4. All these generators have three things in common:

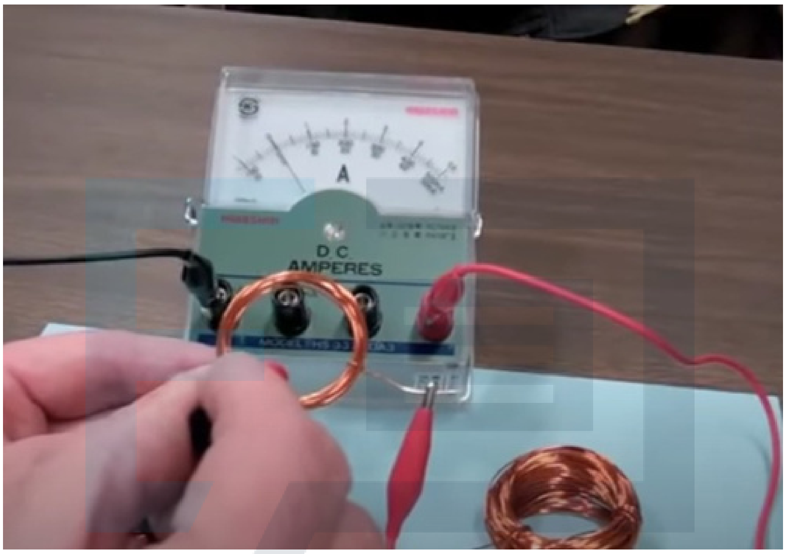
   a. A magnetic field (provided by magnets or electromagnets)

   b. A coil of wire

   c. Movement

21.2 The principles of electromagnetic induction

1. Definition: Electromagnetic induction is the process where a changing magnetic field induces an electromotive force (emf) and consequently an electric current in a nearby conductor.
2. An experiment that showcases electromagnetic induction



a. When a magnet is inserted into and removed from the coil, current is induced, as indicated by the ammeter.

b. The faster the movement of the magnet, the greater the induced current.

c. Increasing the number of turns in the coils results in a larger induced current

d. Reversing the magnet to use the opposite pole causes the current to flow in the opposite direction.

e. If the magnet is held stationary relative to the wire or coil, no current flows.

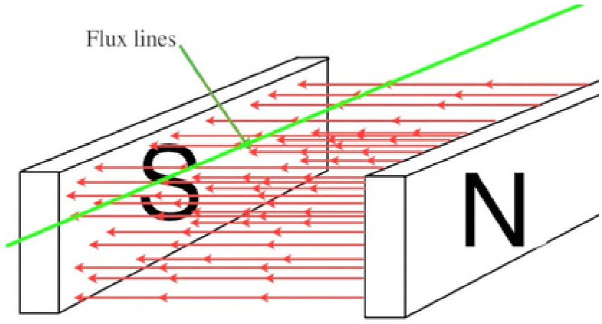
3. Ways to increase the e.m.f induced in a coil or wire:

   a. Use a more powerful magnet.

   b. Increase the speed at which the wire or coil moves relative to the magnet.

   c. Utilize a coil with a greater number of turns of wire. Each turn of wire induces an electromotive force (e.m.f.), and these combine to produce a larger overall e.m.f.

4. Understanding the idea of electromagnetic induction



a. As the wire moves downward between the poles of the magnet, it intersects and cuts across the magnetic field lines. This cutting action induces an electromotive force (e.m.f.) in the wire.

b. Factors influencing the magnitude and direction of the induced e.m.f.:

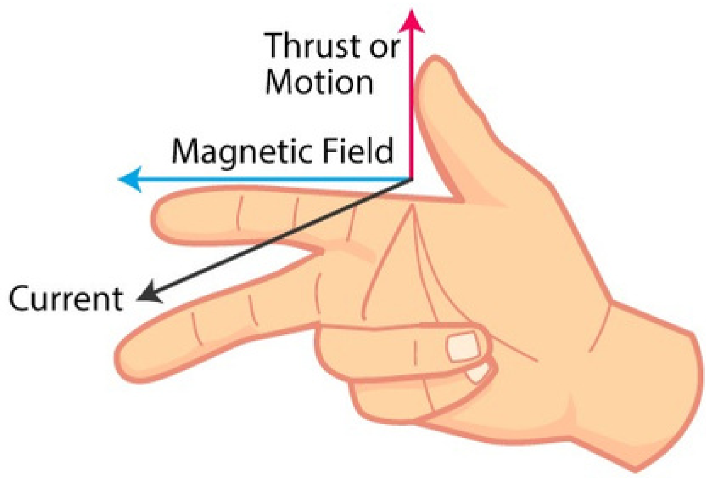
i. When the magnet is stationary, there is no movement to cut the magnetic field lines, resulting in no induced e.m.f.

ii. If the magnet is farther from the wire, the magnetic field lines are more widely spaced, resulting in fewer lines being cut and thus a smaller induced e.m.f.

iii. Moving the magnet quickly increases the rate at which the magnetic field lines are cut, leading to a larger induced e.m.f.

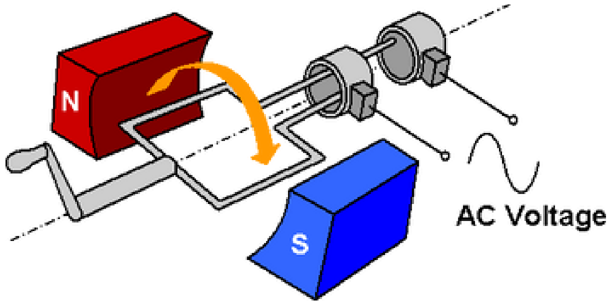
iv. A coil generates a stronger effect than a single wire because each turn of wire within the coil cuts across the magnetic field lines, contributing to the total induced e.m.f.

5. Fleming's right-hand rule – help identify the direction of current generated



21.3 A.C Generator

1. An A.C generator:



2. How it works?

   a. The axle is rotated, causing the coil to spin within the magnetic field, inducing a current.

   b. The induced current in the coil is connected to the external circuit.

   c. An alternating current (AC) generator utilizes slip rings, which rotate along with the coil.

   d. Brushes make contact with the slip rings, allowing them to pick up the same electromotive force (e.m.f.) as the sides of the rotating coil.

3. Why does this generator produce alternating current?

   a. As the coil rotates, each side of the coil passes through the magnetic north pole and then the south pole.

   b. This results in the induced current flowing in one direction first, and then reversing.

4. There are four ways to increase the voltage generated by an a.c. generator:

   a. Turn the coil more rapidly

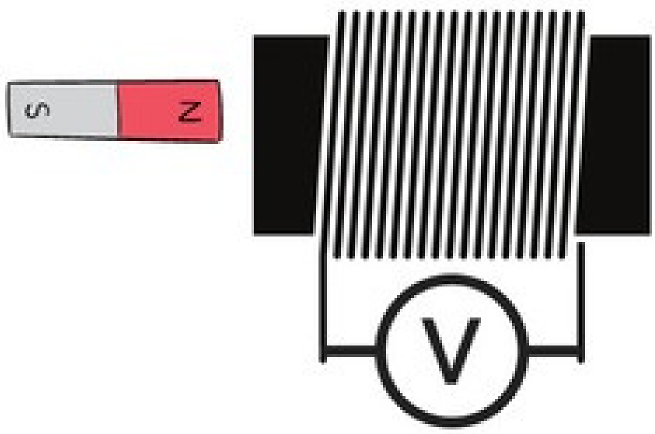
   b. Use a coil with more turns of wire

   c. Use a coil with a bigger area

   d. Use stronger magnets

5. Lenz's law

   a. Given the image below, how do we determine the direction of current flow?



b. Explanation before revealing the solution:

i. The magnet generates a magnetic field around it.
ii. This magnetic field always exerts a force in opposition to the field inducing the current.
iii. When the magnet's north pole approaches the coil, the induced current flows to create a north pole at the end of the coil nearest to the magnet.
iv. The two north poles repel each other, necessitating the pushing of the magnet towards the coil and the expenditure of energy (work).
v. The energy expended in pushing the magnet is transferred to the current induced in the coil.

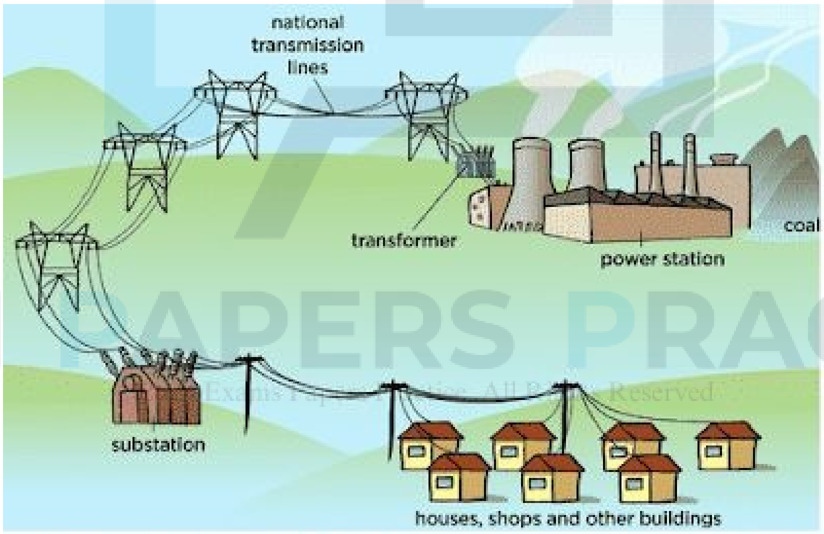
c. We now know the pole of the magnetic field of the induced current, we can find out the the direction of current flow using right hand grip rule.

d. Lenz's law

Lenz's Law states that the direction of the induced electromotive force (emf) and hence the induced current in a conductor will be such that it opposes the change in magnetic flux that caused it, thereby obeying the conservation of energy principle.

21.4 Power lines

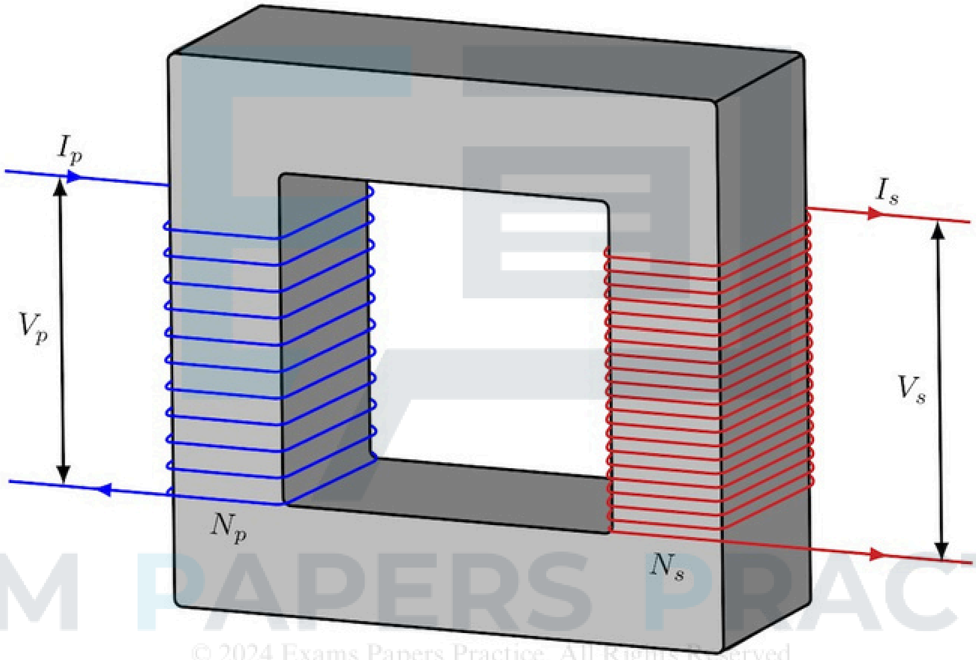
1. Power stations are often located far from the places where the electricity they generate is consumed.
2. How it works:
    a. High-voltage electricity departs from the power station.
        i. Reason: This reduces energy losses caused by heating in the cables.
    b. To mitigate risks to people, this electricity is typically transmitted through cables known as power lines, which are suspended high above the ground between tall pylons.
    c. Networks of pylons carry these power lines across the countryside, directing electricity toward urban and industrial areas where it is needed.
    d. This entire infrastructure forms a country's national grid.



    e. As the power lines approach the areas of consumption, they enter local distribution centers. Here, the voltage is decreased to a safer level, and the electricity is transmitted through additional cables to local substations.
    f. Within the substation, the voltage is further reduced to the standard local supply voltage, typically around 230 V.

21.5 Transformers

1. A transformer increases or decreases voltage levels between circuits through electromagnetic induction based on the ratio of turns in its primary and secondary coils.
2. Structure of a transformer:
   a. Primary coil: The incoming voltage Vp is connected across this coil.
   b. Secondary coil: This provides the voltage Vs to the external circuit.
   c. An iron core: This links the two coils.



3. Both voltages involved are alternating voltages, as transformers only function with AC (alternating current).
4. Power stations typically generate electricity at 25 kV, which needs to be converted to the grid voltage of 400 kV using transformers. This involves increasing the voltage by a factor of 16, meaning there are 16 times as many turns on the secondary coil as on the primary coil.
5. There are two types of transformers:
   - A step-up transformer increases the voltage, achieved by having more turns on the secondary coil than on the primary coil.
   - A step-down transformer decreases the voltage, accomplished by having fewer turns on the secondary coil than on the primary coil.

6. Equation relating voltages and number of turns in each coil:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

Worked Example 1

There are large transformers between power stations and transmission cables. One such transformer has 1000 turns on its primary coil and 20000 turns on its secondary coil. The voltage across its primary coil is 30 kV.

a. State what type of transformer this is.

b. Calculate the voltage across its secondary coil.

7. How does a transformer work?

- Main reason: Electromagnetic induction

a. The primary coil carries alternating current, creating an electromagnet with an alternating magnetic field.

b. The core conducts this alternating magnetic field to the secondary coil.

c. The secondary coil, being in a changing magnetic field, becomes a conductor.

d. This induces a current in the secondary coil.

8. When direct current (DC) is applied to a transformer, there is no output voltage generated. This occurs because the magnetic field produced by the primary coil remains constant. Without a changing magnetic field passing through the secondary coil, no voltage is induced in it.

21.6 Calculating power losses

1. Recall the power formula:

P = VI

2. Benefits of using high voltages. It means that the current flowing in the cables is relatively low, and this wastes less energy.
3. We can calculate the rate of energy loss in the cables using the formula below:

P = I2 R

Worked Example 3:

A 15 kW generator provides an output of 6 kV. This power is transmitted to a workshop using cables with a resistance of 25 ohms. Calculate:

a. The power lost in the cables.

b. The effect of employing a transformer to increase the output voltage to 15 kV, assuming the power output remains constant.

4. If a transformer is 100% efficient, no power is lost in its coils or core. Well-designed transformers typically waste only about 0.1% of the power transferred through them. This efficiency allows us to establish an equation linking the primary and secondary voltage to the primary and secondary current.

$V_1 I_1 = V_2 I_2$

Worked Example 4:

A laboratory power supply unit provides an output voltage of 15 V. It is connected to a 120 V mains supply. The unit utilizes a transformer. The output current from the power supply is 4 A. Calculate the current supplied to the primary coil of the transformer in the power supply unit, assuming ideal transformer operation with no energy losses.

PYQ 1

Fig. 10.1 shows the basic parts of a transformer.

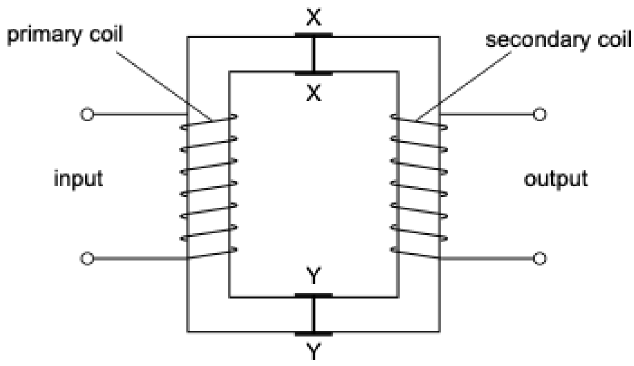


Fig. 10.1

(a) Use ideas of electromagnetic induction to explain how the input voltage is transformed into an output voltage. Use the three questions below to help you with your answer.

What happens in the primary coil?

....

....

....

....

What happens in the core?

....

....

What happens in the secondary coil?

....

....

.... [5]

(b) State what is needed to make the output voltage higher than the input voltage.

.... [1]

(c) The core of this transformer splits along XX and YY. Explain why the transformer would not work if the two halves of the core were separated by about 30 cm.

....

.... [1]

(d) A 100% efficient transformer is used to step up the voltage of a supply from 100 V to 200 V. A resistor is connected to the output. The current in the primary coil is 0.4 A.

Calculate the current in the secondary coil.

current = ... [2]

Electromagnetic induction can be demonstrated using a solenoid, a magnet, a sensitive ammeter and connecting wire.

(a) In the space below, draw a labelled diagram of the apparatus set up to demonstrate electromagnetic induction. [2]

(b) State one way of using the apparatus to produce an induced current.

....

....[1]

(c) Explain why your method produces an induced current.

....

....

....[2]

(d) Without changing the apparatus, state what must be done to produce

(i) an induced current in the opposite direction to the original current,

....

....

(ii) a larger induced current.

....

....

[2]

[Total : 7]

2	(a (i)	a.c. input causes constantly changing current through co magnetic field formed in or around coil constantly changing magnetic field	B1 B1 B1	[M2]
	(ii)	(changing) magnetic field transferred to secondary coil	B1	
	(iii)	(changing) magnetic field cuts secondary coil induces e.m.f.	B1 B1	[3]
	(b)	more turns on secondary (than on primary)	B1	[1]
	(c)	no transfer of magnetic field from primary to secondary	B1	[1]
	(d)	Vp.Ip = Vs. Is or 100 x 0.4 = 200 x Is Is = 0.2 A	C1 A1	[2] Total [9]

(a)		Solenoid ends connected to meter, both labelled One magnet in correct position to enter / leave solenoid, labelled	B1 B1	2
(b)		Push magnet into coil / pull out / move near end of coil	B1	1
(c)		(magnet has / produces) magnetic lines of force / magnetic field lines cut (coils of) solenoid / coils / wires	B1 B1	2
(d)	(i)	Pull magnet out of coil / reverse effect to answer (b)	B1	
	(ii)	Move magnet faster or effect in (a) faster	B1	2 [7]