3 ELECTROMAGNETIC INDUCTION

What we have already learnt

- **Magnetic field:** The space around a magnet where its influence is felt.
- **Magnetic flux:** The total number of lines of force around a magnet is called magnetic flux.
- **Electromagnet:** It is an arrangement of a soft iron piece inside a solenoid. The magnet loses its property when the current in the solenoid ceases.
- **Galvanometer:** The device used to detect the presence and direction of a feeble current.
- **Electric power :** The amount of electrical energy developed in one second. The electric power in a circuit is calculated using the equation P = VI.
- For a current to flow through a conductor there should be a potential difference between its ends.

You may have done experiments which show that an electric current produces a magnetic field.

Christian Oersted's discovery of magnetic field around a current carrying conductor was quite accidental. If a flow of electric current can produce a magnetic field then why can't a magnetic field produce an electric current? An attempt to find an answer to this lead Michel Faraday to the invention of generators. You know that the conversion between electrical and mechanical energy is the principle behind the working of generators and electric motors. They play an important role in reducing the work load and in enhancing the facilities in our life. Hence this chapter is important in familiarizing the parts and working principle of the devices such as generator, electric motor, transformer, microphone, loud speaker etc.

3.01 A form of energy which ushered in a new era

In modern life the electricity is indispensible in all fields of life. Can you imagine a world without electricity? The possibility of large scale production, the facility of transmission and control, the possibility of easy conversion to different forms of energy are the peculiar advantages of electricity.

Prepare a list of devices used for the production of electricity.

- Torch cell
- Cycle dynamo
-

Electrical energy is to be produced in large scale to satisfy our increased energy demands. For that, huge generators are used. Let us do an experiment to understand the principle of a generator.

3.02 Electromagnetic induction

Make a solenoid having a large number of closely wound turns of insulated copper wire. Connect its ends to the terminals of a galvanometer. Bring the coil swiftly to one pole of a magnet. Observe the deflection in the galvanometer. What happens when the coil is suddenly taken off?

Keeping the coil at rest bring one end of a magnet swiftly to the coil and then take it back at the same speed. Note down in your science diary the direction of deflections in the galvanometer.

The needle deflects to opposite directions in the two different situations and suddenly comes back to the initial position.

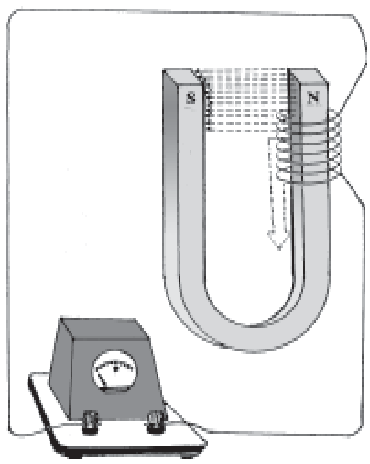


figure 3.1(a)

When a solenoid swiftly moves in a strong magnetic field, the galvanometer needle deflects indicating the flow of a current.

Haven't you seen that a temporary current has flowed through the solenoid.

You know that the magnetic flux lines have a basic property of magnetism. What happens to the magnetic flux lines when a magnet is moved into a solenoid or when a solenoid moves in the vicinity of a magnet?

In the above situations a temporary electric current was generated either because the flux lines were cut by the moving coil or the flux lines linked with the coil were changed.

The process of inducing an emf in a conductor whenever the magnetic flux linked with it changes, is known as electromagnetic induction.

The emf so developed is called induced emf and the current so obtained is called induced current.

Let us find out the factors which affect the induced emf?

Repeat the above experiment by changing the number of turns of the coil as

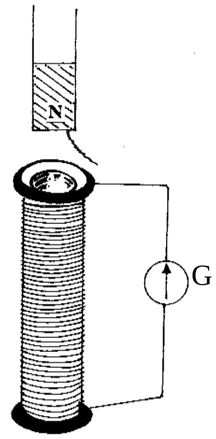


figure 3.1(b)
Magnet moved into a solenoid

well as the strength of the magnet and note down the results of your observation in Table 3.1.

From the table, it is clear that the induced emf increases when the speed of motion, the strength of the magnetic field and the number of turns increase.

The induced emf developed in a conductor is equal to the rate of change of flux linked with it. This is Faraday's Law of electro magnetic induction.

Activities	Observed results
A magnetic pole is suddenly introduced into a solenoid and withdrawn from it.	
The same pole is slowly introduced and slowly taken back.	
Moving a strong magnetic pole into and out of a solenoid.	
Moving a magnetic pole into a solenoid of fewer turns.	
Moving the magnetic pole at the same speed into a coil of large number of turns.	

Table 3.1

3.03 Alternating current (AC); Direct current(DC)

Connect the terminals of a weak cell to a galvanometer. Observe the deflections of the needle. Remove the cell and connect a solenoid to a galvanometer. Observe the deflections of the needle by continuously moving a magnet into and out of the solenoid (fig 3.1b). What changes have you seen?

The needle deflects only in one direction when the galvanometer is connected to a cell.

Thus a current flowing only in one direction is called direct current (DC).

The needle is seen deflecting to either side when the galvanometer is connected to the solenoid in the above experiment.

The direction of the electric current produced by the movement of the magnet in opposite directions continuously changes. Thus the current which changes its direction at regular intervals is called alternating current. (AC).

3.04 AC generator (Alternator)

We have seen that electric current is produced only momentarily in the experiment conducted using a solenoid and a magnet. Can we modify this arrangement for continuous generation of electricity?

The device which produces electricity on the basis of electromagnetic induction by the continuous motion of either the solenoid or the magnet is called a generator.

Let us see the working of a model AC generator. Record the parts of the generator by observing the figure 3.2.

- Armature

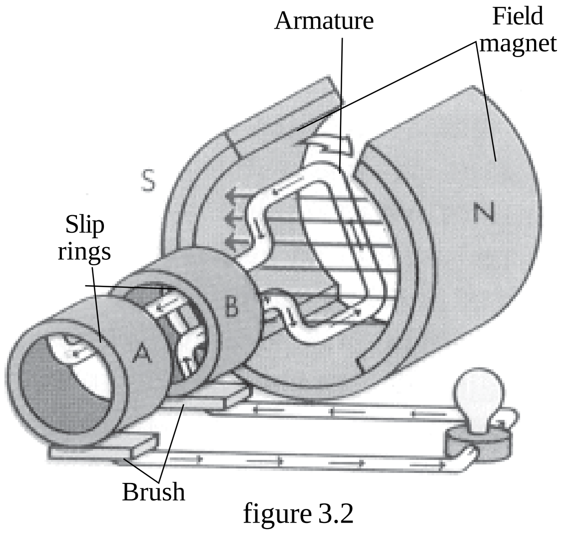


figure 3.2

AC generator

- Field magnet
-

An armature is an arrangement of an insulated conducting wire wound around a soft iron piece. The armature is continuously rotated by means of mechanical energy. Figure 3.3 shows the different stages of the rotation of the armature between the pole ends of the field magnet. Find out answers to the questions given below by analysing the graph along with the figure (3.3).

- There is no electricity in the armature coil at the stages 1,3 & 5.Why?
- Why is the electricity obtained at the stages 2 & 4 the maximum?
- What is the reason for the different directions of the current in stages 2 and 4?
- What are the angles of the rotation at which the emf in the armature is maximum?
- How do the direction and the magnitude of the emf change during one rotation of the armature?

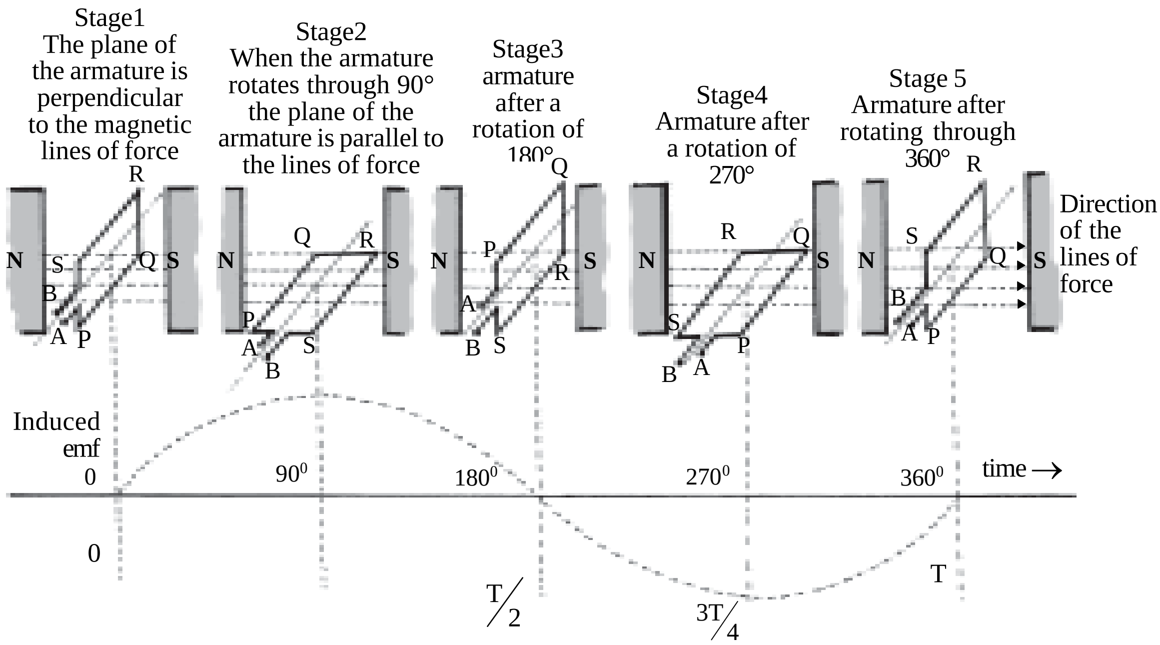


figure 3.3
The different stages of the rotation of the armature

The induced current developed in one direction during the first half rotation of the armature of the AC generator and the induced current developed in the opposite direction during the next half of the rotation constitute one cycle of an AC.

The number of cycles in one second is called the frequency of AC. Do you know the unit of frequency?

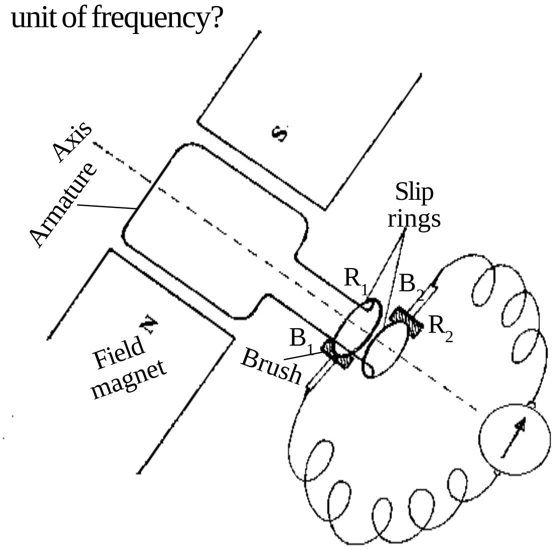


figure 3.4
The parts of an AC generator

The frequency of AC in our houses is 50 Hz. What do you understand from this?

3.05 DC generator

We use AC for domestic as well as industrial purposes. But AC is not suitable for certain other purposes. Can you find out the situations where DC is necessary?

- Electroplating
-

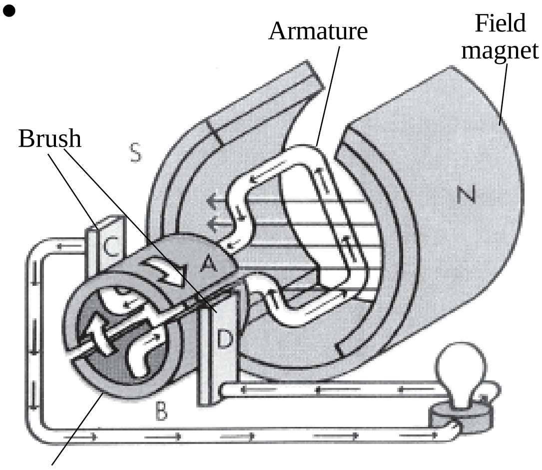


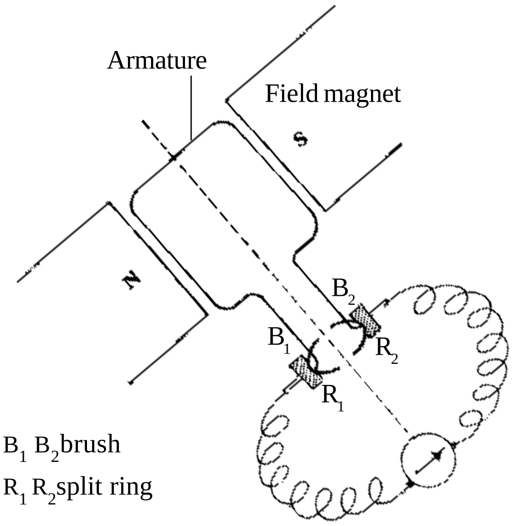
figure 3.5
Parts of a DC generator

Let us familiarise ourselves with the model of a DC generator.

Note down the parts of a DC generator in 'Science diary' by observing the figure 3.5

- Armature
-
-

Note down in the science diary the similarities and differences between an AC generator and a DC generator by comparing their structures.



B_1 B_2 brush
R_1 R_2 split ring

figure 3.6 (a)
DC Generator at its first half of rotation

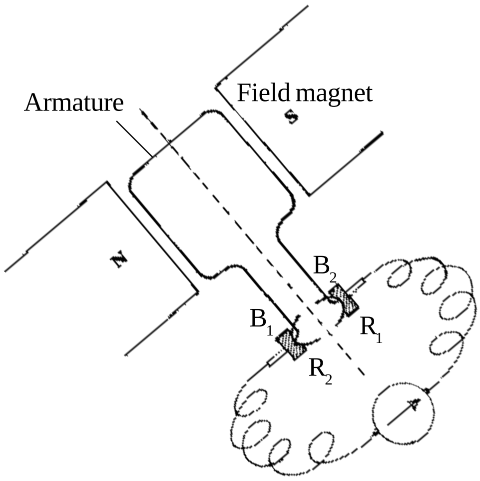


figure 3.6 (b)
DC Generator at the second half of rotation

Let us see how the electric current from a DC generator flows in one direction in the external circuit.

The positions of the two half rotations of the armature in a DC generator are given in the figure (fig 3.6)

Here the AC induced in the armature is converted into DC in the external circuit by an arrangement called split ring commutator. The flux cut in the first half of the rotation is in one direction and in the opposite direction during the second half rotation. Hence the direction of flow of current in the armature changes. When the direction of the current in the armature changes during the successive half rotations, the conatct of one half of the split ring shifts from one brush to the other. So the direction of the current in the external circuit does not change.

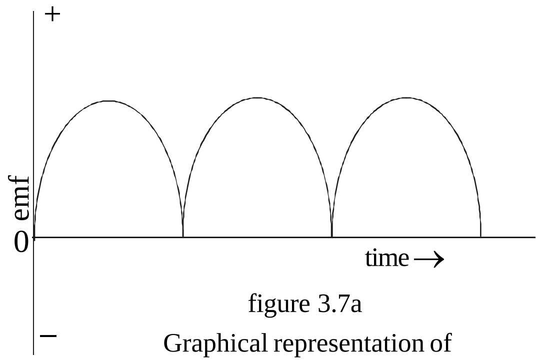


figure 3.7a
Graphical representation of emf from a DC generator

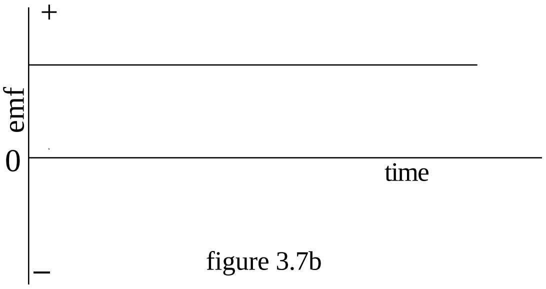


figure 3.7b
Graphical representation of emf from a battery

Can you find out the difference between the emf obtained from a battery and that from a DC generator by drawing their graphs?

3.06 The force experienced by a current-carrying conductor in a magnetic field

Does a magnetic needle deflect when it is placed near a current carrying conductor? You have learnt that induced current develops in a solenoid when it is moved in a magnetic field. What is the result when a current is passed through a conductor placed in a magnetic field? Let us experiment it.

Suspend a copper rod by means of thin conducting wires as shown in figure 3.8. Connect the two ends of the conductors to the terminals of a battery through a key. The copper rod is free to move freely in between the poles of a strong magnet. Then electricity is passed through it. What happens to the copper rod? Observe it also by changing the direction of current?

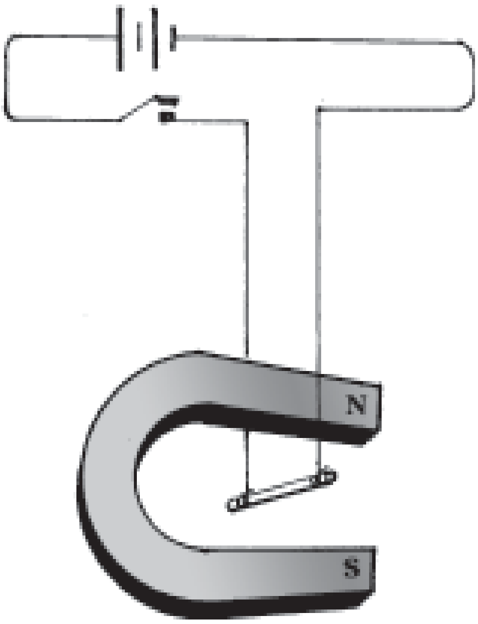


figure 3.8
A current carrying conductor gets deflected when it is suspended freely in a magnetic field

Note down the inferences after discussing your observations.

- A current carrying conductor in a magnetic field experiences a force. Hence the conductor moves in the direction of force. This is the principle of electric motor.

In the above experiment the copper rod was free to oscillate. But what will be the type of motion when an electric current is passed through a coil which is free to rotate about its own axis is placed in the position of the copper rod. This principle is used in the making of an electric motor.

3.07 Electric motor

Let us see the working of a motor run by battery. Note down the parts of an electric motor by observing the figure 3.9

- Armature
-

As in a generator, the electric motor also contains an armature and a field magnet. An

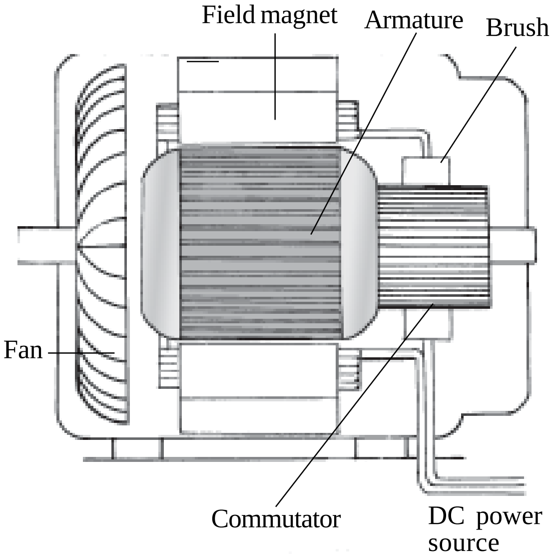


figure 3.9a
The parts of a DC electric motor

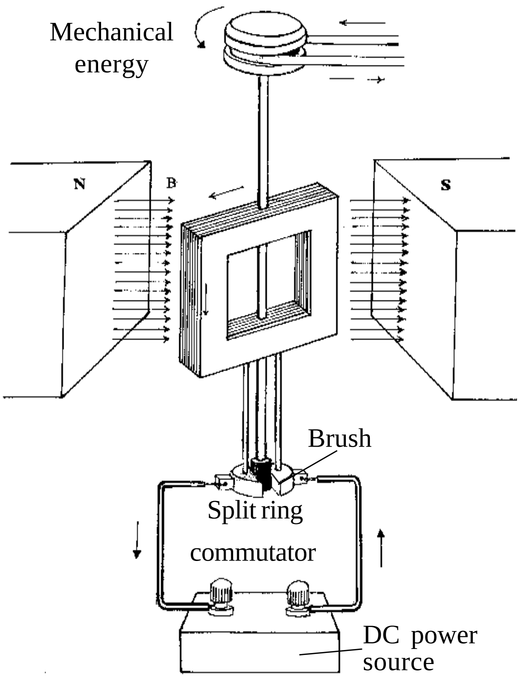


figure 3.9b
DC electric motor

armature can freely rotate about its axis. You have already learnt the principle behind the electric motor that the armature rotates when electricity is passed through it. The rotating armature gets mechanical energy through a shaft connected to the axis of the armature.

- Note down the similarities in the structure of a motor and that of a generator in your science diary.
- Note down the energy conversion occurring in motors and generators.
- Prepare a list of devices in which the principle of motor employed.

A machine that made revolution!

We can say that there is nothing like an electric motor which has influenced and facilitated our lives by the single pressing of a switch. Today, just by merely pressing a switch, we can do more efficiently and quickly a lot of activities which were earlier done with great physical effort and by employing animals. This is achieved due to the invention of electric motor. Motors are the basic units of the domestic appliances such as fan, mixi, grinder, pumpset and small and huge machines in factories.

You have learnt about the electromagnetic induction and the mechanical effect of electricity. Let us familiarise some of the devices which work on the basis of these.

3.08 Moving coil loudspeaker

A loudspeaker reproduces sounds in audio visual equipments such as radio, television, tape recorder etc. Observe the parts of a damaged loudspeaker.

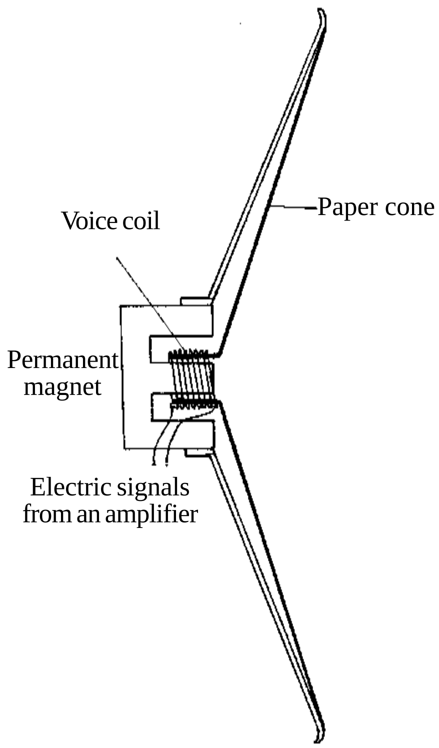


figure 3.10
Parts of a loud speaker

Note down the parts of a loud speaker by observing the figure.

- Permanent magnet
-

A voice coil placed between the poles of a permanent magnet is the important part of a loudspeaker. A paper cone or a diaphragm is attached to this coil. The electrical signal corresponding to the variations of sounds from the microphone is amplified by an amplifier and is fed to the voice coil. The voice coil placed in the magnetic field vibrates in accordance with the intensities of the electrical signals. These vibrations induce vibrations on the paper cone attached to the coil causing vibrations to the air around it. As a result, the original sound is reproduced more loudly.

Note down the answers to the questions given below.

- Will there be any vibration if the current reaching the voice coil is without any fluctuation?
- What is the energy conversion taking place in a moving coil loud speaker?

3.09 Mutual induction

An insulated copper wire is wound around one end of a soft iron core and the ends of the coil are connected to a battery through a switch. Another insulated copper wire is wound around the other end of the core. Connect the ends of this coil to a galvanometer. Of these, the circuit which is connected to the battery is called primary circuit and that connected to the galvanometer is called secondary circuit. Note down the

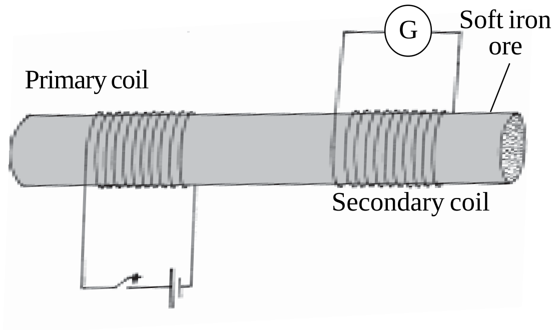


figure 3.11

An experiment to explain mutual induction

deflections in the galvanometer when the primary circuit is switched on or off.

Why does the galvanometer needle deflect? That is because an emf is produced in the secondary. Then how is it produced? Is this the emf of the cell?

When there are two nearby coils the variation of current in one of them produces a change in the magnetic flux around it. The second coil is situated in this region of varying magnetic flux. Therefore by electromagnetic induction an emf is induced in the secondary coil. This phenomenon is called mutual induction.

3.10 Self induction

Make a circuit containing a bulb, a solenoid, a 12 V DC battery and a switch as shown in figure 3.12 (a). Observe the intensity of light by switching on the circuit. Connect a 12V AC source to the circuit in the place of

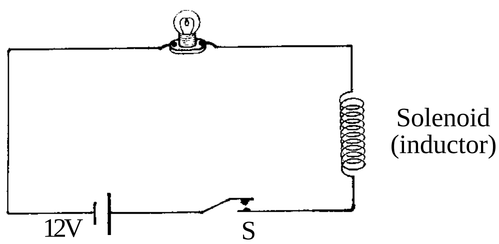


figure 3.12(a)

the 12V DC battery. Is there any change in intensity of light? Observe.

You have seen that the intensity of light decreases while using an AC in the circuit. There is a change in magnetic flux linked with the solenoid when AC flows through it. Due to this change in flux an induced emf developes in the solenoid. This emf is opposite to the emf applied in the circuit. Therefore the resultant emf in the circuit decreases. The brightness of the bulb also decreases.

Self induction is the phenomenon of inducing an emf in a coil caused by the variations of magnetic flux produced by a varying current in the same coil.

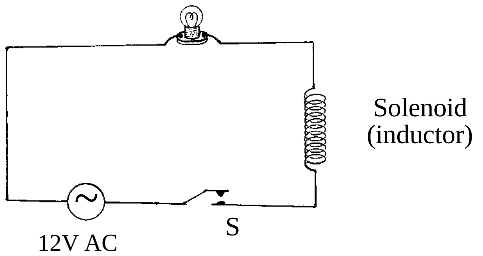


figure 3.12(b)
An experiment to demonstrate self induction

In the above experiment, a soft iron rod is slowly introduced into the coil and then taken out from it. Record your observations of these two cases.

Inductors are coils which can oppose the changes of current in a circuit. They are used for reducing current in AC circuits without any loss of electrical energy. For these purposes resistors can also be used. But while using resistors electrical energy is wasted in the form of heat.

3.11 Transformer

Arrange two insulated solenoids over a soft iron core as shown in figure 3.13. (both must have almost the same number of turns).

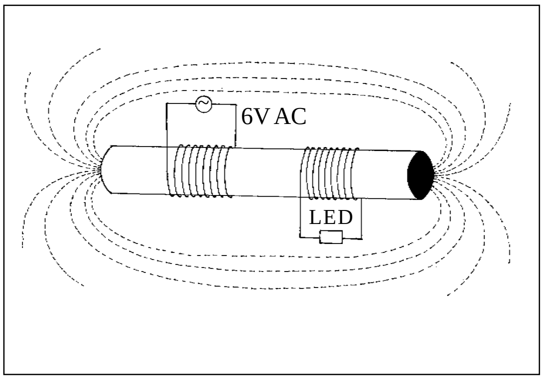


figure 3.13
Demonstrattion of the working principle of a transformer

Connect one of them to 6V AC supply through a switch. The ends of the other coil are connected to an LED. The coil which is connected to the AC supply is called primary coil and that connected to the LED is called secondary coil.

The LED glows when AC passes through the primary coil. Can you explain the reason ?

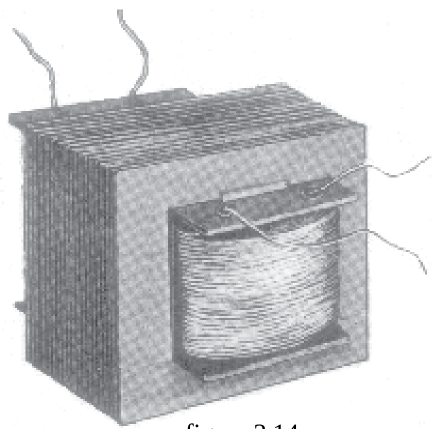


figure 3.14
Transformer

Secondary coil is placed in a magnetic field of continuously changing direction.The variation in the magnetic flux causes an induced emf in the secondary. In a transformer electrical energy is transferred from one circuit to another by electromagnetic induction.

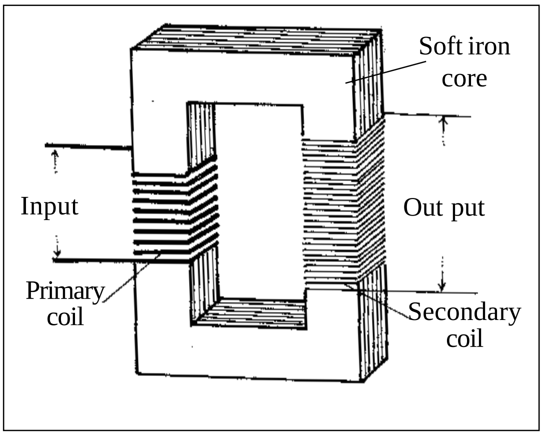


figure 3.15 (a)
Step-up transformer

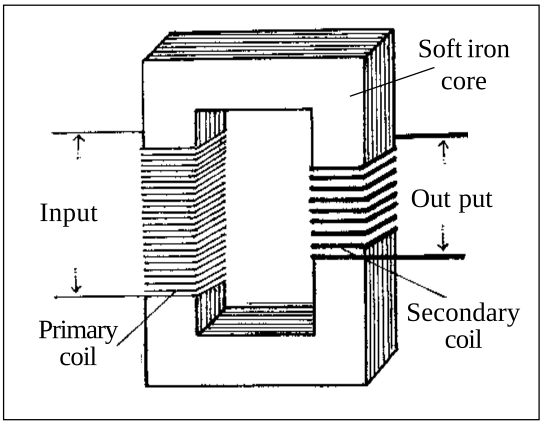


figure 3.15 (b)
Step-down transformer

There are two types of transformers in use - step-up transformers and step-down transformers. Observe the figures and record in table 3.2 the structural differences between a step-up transformer and a step-down transformer.

Step-up transformer	**Step-down transformer**
•	•
•	•
•	•

Table 3.2

The rate of change of flux in a coil depends also on the number of turns in it. Therefore the emf induced in a coil is directly proportional to the number of turns in it. If the number of turns in the secondary is twice that of primary then the output voltage will also be doubled.

The voltages in the primary and secondary are directly proportional to the respective number of turns in them.

Mathematically,

V_S : Voltage in the secondary

V_P : Voltage in the primary

N_S : Number of turns in the secondary

N_P : Number of turns in the primary

Fill in the blanks in the tabular columns given below.

Primary coil		**Secondary coil**	
No. of turns N_P	Voltage V_P	No. of turns N_S	Voltage V_S
400	230	200	115
100	__	1000	500
800	240	__	480
__	12	2000	60

Table 3.3

Let us solve the problem given below.

- To wind a step-down transformer to get an output of 10V by applying an input voltage of 250 V, how many turns are required in the secondary coil if the number of turns in the primary is 4500?

- Let us find the relationship between the voltages and current in the primary and the secondary of a transformer. Let the primary current be I_p and secondary current I_s, then the power in the primary $= V_p \times I_p$ so the power in the secondary is $V_s \times I_s$.
  If there is no energy loss, we get $V_p \times I_p = V_s \times I_s$
- In a step down transformer in which coil is the electric current more? What about a step up transformer?

You know that by using a transformer DC voltage cannot be increased. But there is a device also to increase the DC voltage. Such a device is called an induction coil.

The electromagnetic phenomenon in living beings

Whenever there is electric current there is a magnetic field. Even the slightest flow of ions through the nerve cells in our body will generate a magnetic field. When we touch certain objects eletrical signals are sent to the concerned muscles by the nerves. These signals create temporary magnetic field. This magnetic field is only one billionth of the earth's magnetic field. Brain and heart are the major organs in the human body which produce magnetic field of this kind. The magnetic fields of this type help us get pictures of the parts of our body in an MRI. (Magnetic Resonance Imaging) scan

3.12 Moving coil microphone

Moving coil microphone is a device which works on the principle of electromagnetic induction. In this sound energy is converted into electrical energy.

Note down its main parts observing the figure.

- Permanent magnet
-

A coil placed in a magnetic field is the main part of it. A diaphragm is attched to this coil. The coil vibrates with the vibrations of the diaphragm when sound waves fall on it. At that time, electrical signals are produced in it in accordance with the sound.

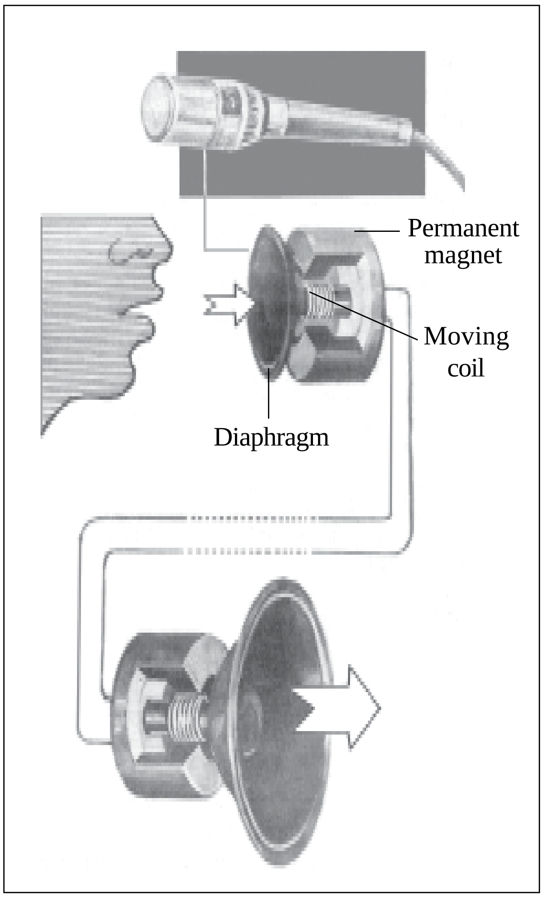


figure 3.16
Microphone and loudspeaker

Write down the answers to the questions given below.

- What are the similarities between the structures of the microphone and that of the loud speaker?
- How are electrical signals produced when the voice coil vibrates in accordance with the sound waves?
- Does the induced current have the same direction and strength?

Summary

- **Electromagnetic induction:** The process by which an emf is induced in a conductor when the magnetic flux linked with it changes.
- **Electric generator:** The device which converts mechanical energy into electrical energy.
- **Alternating current(AC):** Electric current which changes its direction at regular intervals of time.
- **Electric motor:** A device which converts electrical energy into mechanical energy.
- **Principle of a motor:** A current carrying conductor in a magnetic field experiences a force and hence it deflects. This is the principle of a motor.
- Generator, transformer, moving coil microphone etc work on the principle of electromagnetic induction.
- A moving coil loudspeaker works on the principle of electric motor.

More activities for you

1 Prepare a list of different electrical equipments. Note down the working principle of each.

2 The characteristics of electric current from three different sources are given below. Write down the name of source and draw the time-emf graph of each.

Characteristics of electric current	Source	Graphical representation
Flows in opposite directions with continuous variations		
Continuously increases and decreases, but flows in the same direction.		
Flows in the same direction without any change.		

3 Prepare a list of electrical equipments in which inductors are used.

4 Collect damaged loudspeakers and microphones. Open them and note their parts. Prepare and present a report.

5 A transformer without power loss contains 10000 turns in primary and 500 turns in secondary. The primary voltage is 240 V and the strength of electric current is 0.1A. Calculate the voltage and current in the secondary.

6 'In the armature of a DC generator alternating current is developed.' Is this statement true? Why?

7 Try to understand the structure and working of a transformer by interviewing KSEB officials. Prepare a report and present it.

8 'Electricity as a form of energy ushered in a new era.' Organise a seminar on this subject.

9 An electric source is connected to the terminals of an electromagnet. How can you identify the source as AC or DC by using a magnetic needle?

10 We have already understood the structure and working of a moving coil microphone. There are other microphones in use based on other principles. Prepare a report on it and present it in your class.

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