CHAPTER 4

Electromagnetism

How are magnetic forces used to produce rotation in an electric motor?

What is a brushless motor?

How can the concept of electromagnetic induction be applied to benefit human beings?

Why are transformers used in the transmission and distribution of electricity?

You will learn:

Learning Standards and List of Formulae in Chapter 4

Information Portal

http://bit.ly/31oQxJK

The drop tower is a high technology theme park equipment based on the concept of electromagnetic induction. The passengers on the drop tower will drop from a great height and experience free fall at high speed. They are then slowed down by an arrangement of permanent magnets fixed under their seats and copper strips on the lower section of the drop tower. The motion of the permanent magnet passing the copper strips will activate electromagnetic braking. This can be explained by the concept of electromagnetic induction.

Importance of the Chapter

Knowledge about electromagnetism is important because magnetic forces, electromagnetic induction and transformers have wide applications and affect various aspects of our daily life. Magnetic forces are used in various types of motors such as small electric motors in fans and modern electric motors in modern electric vehicles. The principle of electromagnetic induction is applied in electric generators and transformers for the purpose of generation and transmission of electric power from the power station to the consumer. Various new innovations that use the concept of electromagnetism are being developed by scientists and engineers.

Futuristic Lens

http://bit.ly/2CTNa3X

The concept of electromagnets is not only used to slow down motion but also to accelerate the motion of objects to very high velocities. For example, hyperloop transportation uses linear electric motors (without rotation) to accelerate vehicles moving in low pressure tubes. Transportation on land at speeds comparable to the speed of aircraft may become a reality in the near future.

4.1 Force on a Current-carrying Conductor in a Magnetic Field

Do you know that an electric train as shown in Photograph 4.1 uses a large electric motor while a smart phone uses a small motor? The function of most electric motors is based on the effect of a current-carrying conductor in a magnetic field.

Photograph 4.1 *Electric train*

SCAN ME
EduwebTV: Force on a current-carrying conductor
http://bit.ly/3glVNBT

Activity 4.1

Aim: To study the effect on a current-carrying conductor in a magnetic field

Apparatus: Low voltage direct current power supply, U-shaped steel yoke, a pair of Magnadur magnets and retort stand

Materials: Two copper rods without insulation and copper wire (s.w.g. 20 or thicker) without insulation

Instructions:

1. Set up the arrangement of apparatus as shown in Figure 4.1.

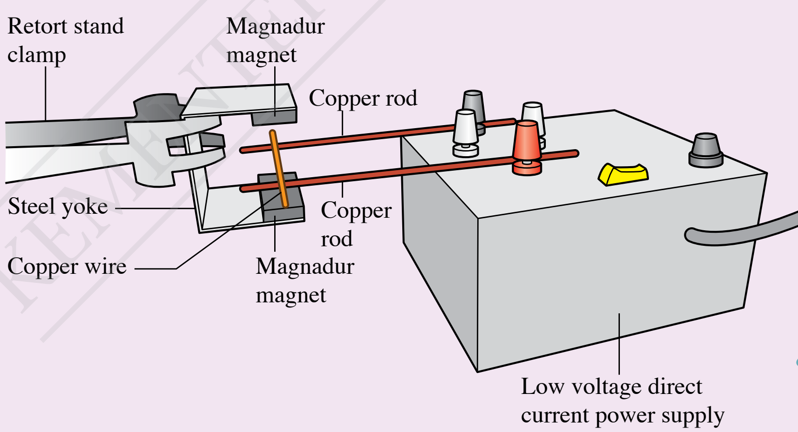


Figure 4.1

SCAN ME
Video on force
http://bit.ly/2CSkOXF

2. Turn on the power supply so that current flows into the copper wire. Observe the movement of the copper wire.
3. Turn off the power supply. Reverse the connections to the power supply so that the current in the copper wire is reversed.
4. Turn on the power supply again. Observe the movement of copper wire.
5. Turn off the power supply. Remove the steel yoke, reverse the poles of the Magnadur magnets and put back the steel yoke.
6. Turn on the power supply and observe the movement of copper wire.

Discussion:

1. Describe the motion of the copper wire when the power supply is turned on.
2. What is the effect on the copper wire when:
   (a) the direction of the current is reversed?
   (b) the poles of the magnet are reversed?
3. State two factors that affect the direction of the force acting on the current-carrying conductor.

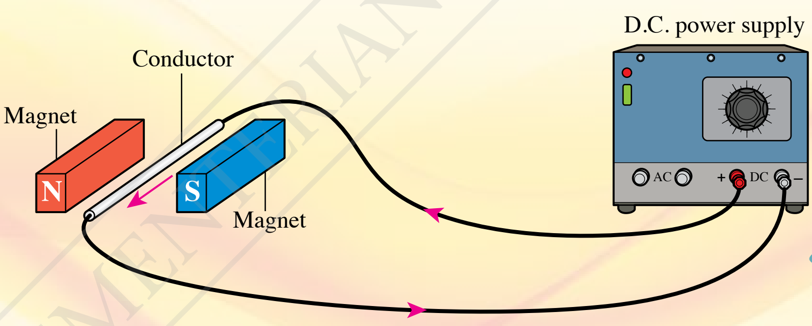
When a current-carrying conductor is placed in a magnetic field, the conductor will experience a force. The direction of the force depends on the direction of the current and the direction of the magnetic field.

SCAN ME
Video on formation of force
http://bit.ly/3jajz5s

Pattern on Resultant Magnetic Field

Figure 4.2 shows a current-carrying conductor that is placed in a magnetic field produced by a pair of Magnadur magnets. What is the direction of the force acting on the conductor?

LET'S RECALL
Magnetic field from the electric current in a straight wire
http://bit.ly/31m7yE4



SCAN ME
Effect on a current-carrying conductor in a magnetic field
https://bit.ly/2Qhj2T6

Figure 4.2 *Current-carrying conductor placed between two magnets*

The force on a current-carrying conductor in a magnetic field is produced by the interaction between two magnetic fields: the magnetic field from the electric current in the conductor and the magnetic field from the permanent magnet. The two magnetic fields combine to produce a resultant magnetic field that is known as a catapult field. The pattern of the catapult field will show the direction of the force acting on the conductor.

Activity 4.2

ISS / ICS

Aim: To observe magnetic field pattern through a computer simulation

Instructions:

1. Carry out a Think-Pair-Share activity.
2. Scan the QR code to observe the computer simulation that shows the method of drawing the pattern of the resultant magnetic field.
3. Scan the QR code and print the worksheet.
4. Based on the computer simulation that you watched, complete the worksheet to show the formation of the catapult field.
5. Label the direction of the force acting on the current-carrying conductor.

SCAN ME
Simulation of magnetic field pattern
http://bit.ly/3gou5Vf

SCAN ME
Worksheet
http://bit.ly/3gjqVC4

Figure 4.3 shows the catapult field formed when a current-carrying conductor is in a magnetic field. A **catapult field** is a **resultant magnetic field produced by the interaction between the magnetic field from a current-carrying conductor and the magnetic field from a permanent magnet**. The catapult field exerts a resultant force on the conductor.

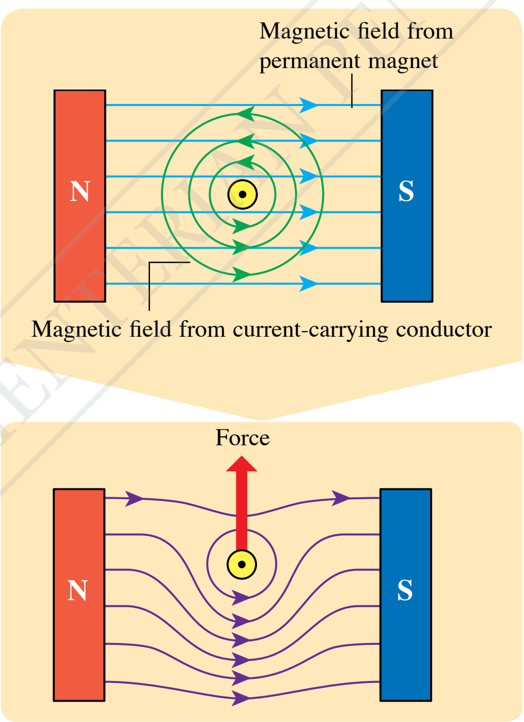
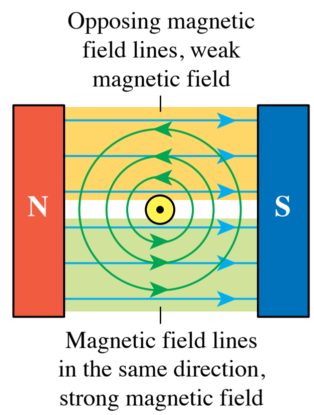


Figure 4.3 *Formation of catapult field*

BRIGHT Info

- For a straight conductor, the direction of the magnetic field is determined by the right hand grip rule.
- For a permanent magnet, the direction of the magnetic field is from north to south.
- The region of weak magnetic field and the region of strong magnetic field is determined as follows:



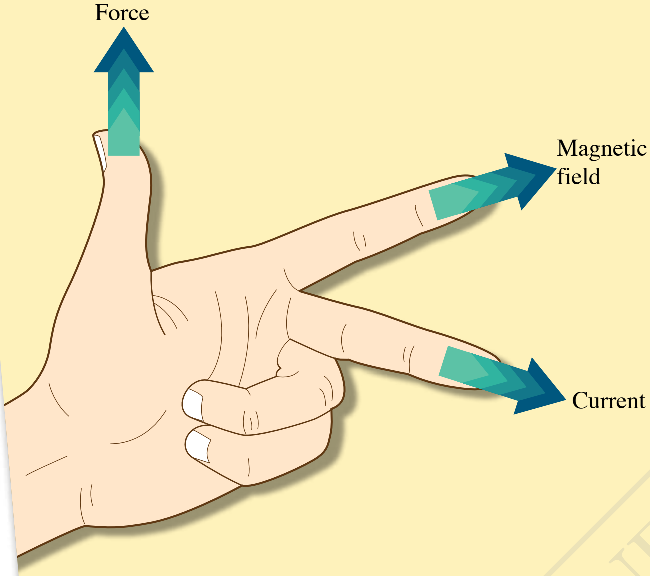
Direction of current out of the plane of the paper

Direction of current into the plane of the paper

LS 4.1.2

The direction of the force on a current-carrying conductor can be determined by using Fleming's left-hand rule as shown in Figure 4.4.

Fleming's left-hand rule



Step 1 Index finger shows the direction of the magnetic field, that is, from north to south.

Step 2 Middle finger shows the direction of the electric current.

Step 3 The thumb will show the direction of the force acting on the conductor. The direction of motion of the conductor follows the direction of the force.

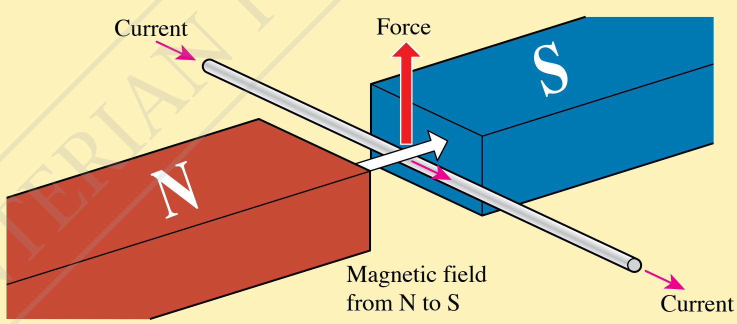


***Figure 4.4** Fleming's left-hand rule to determine the direction of the force*

Factors Affecting the Magnitude of the Force Acting on a Current-carrying Conductor in a Magnetic Field

A large force is required to drive the motor in a washing machine compared to the cooling fan in a notebook computer which requires a smaller force. What are the factors affecting the magnitude of the force acting on a current-carrying conductor in a magnetic field?

Activity 4.3

Aim: To study the factors that affect the magnitude of the force acting on a current-carrying conductor in a magnetic field

Apparatus: Direct current power supply, U-shaped steel yoke, two pairs of Magnadur magnets, electronic balance and retort stand

Materials: Copper wire (s.w.g. 20), crocodile clip and connecting wires

Instructions:

1. Set up the apparatus as shown in Figure 4.5.

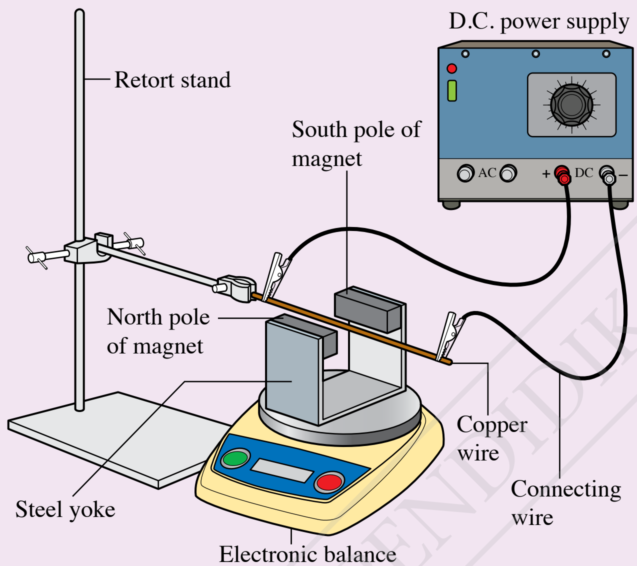


Figure 4.5

2. Adjust the output to 1 V on the D.C. power supply. Reset the reading of the electronic balance to zero.
3. Turn on the power supply and record the reading of the electronic balance. Then, turn off the power supply.
4. Repeat steps 2 and 3 with output voltage 2 V. Record your results in Table 4.1.
5. Add another pair of Magnadur magnets on the steel yoke and repeat steps 2 and 3. Record your results in Table 4.1.

Results:

Table 4.1

Voltage / V	Number of magnets	Reading of electronic balance / g
1	One pair	
2	One pair	
1	Two pairs	

Note

The interaction between the magnetic fields of the current in the copper wire and the Magnadur magnets will produce a catapult field. The catapult field exerts a force vertically upwards on the copper wire. At the same time, the Magnadur magnets experience a reaction force with the same magnitude but in the opposite direction. This force acts on the pan of the electronic balance to give a reading that represents the magnitude of the force. Hence, a larger force will produce a larger reading of the electronic balance.

SCAN ME
Video of force measurement
http://bit.ly/3lf051t

Note

The north pole and the south pole of the Magnadur magnet can be determined by bringing a bar magnet near the Magnadur magnet. Remember that like poles repel while opposite poles attract.

Discussion:

1. What is the relationship between the voltage applied across the copper wire and the current in the wire?
2. How does the magnitude of the current affect the magnitude of the force acting on the current-carrying conductor?
3. What is the effect of the strength of the magnetic field on the magnitude of the force acting on the current-carrying conductor?

From Activity 4.3, it is found that the magnitude of the force acting on the current-carrying conductor in a magnetic field increases when the magnitude of the current and the strength of the magnetic field increases. The effect of the increase in current and the strength of magnetic field on the force can be observed from the height of swing of the copper frame as shown in Figure 4.6.

Brain-Teaser

How can the strength of the magnetic field and the current be increased?

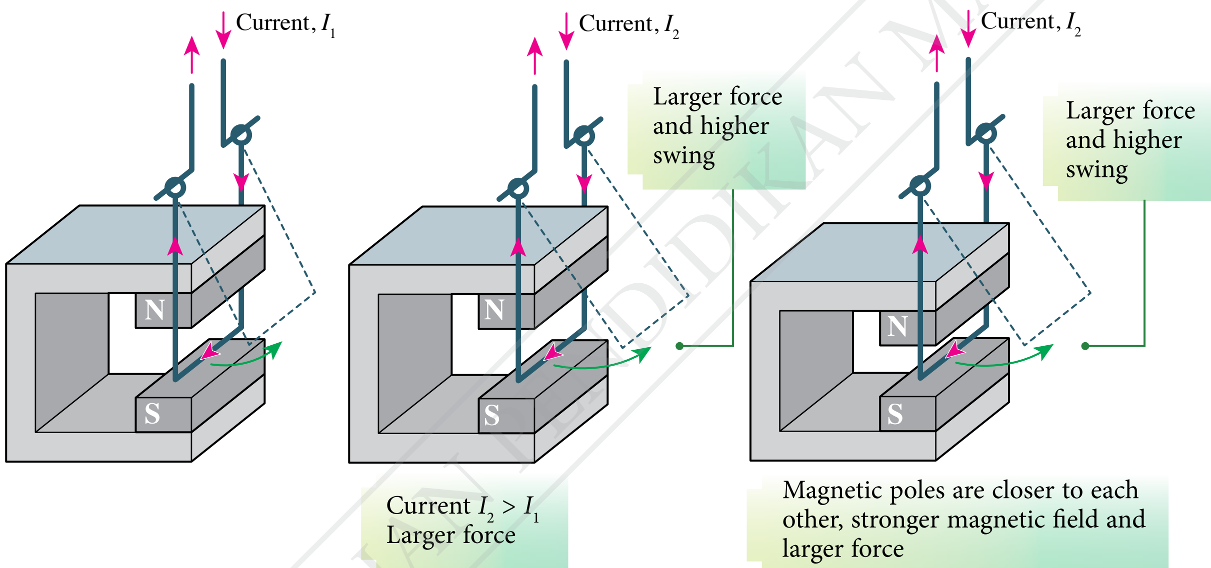


***Figure 4.6** Effects of current and magnetic field on force*

Figure 4.7 shows another way to study the factors that affect the magnitude of the force acting on a current-carrying conductor in a magnetic field. The distance travelled, *d*, by the conductor represents the magnitude of the force. The larger the force, the further the distance travelled by the conductor.

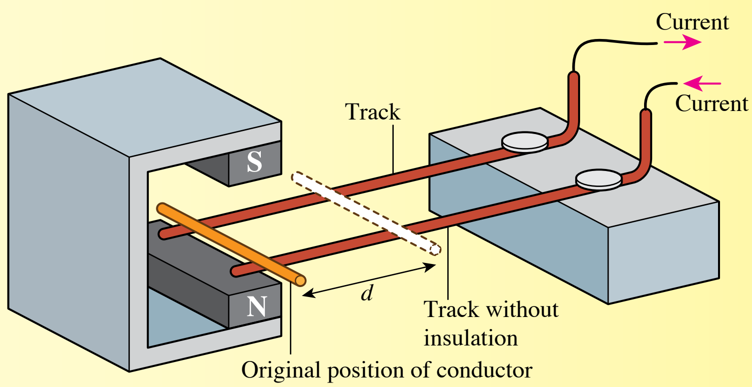


***Figure 4.7** Distance travelled, d, by a conductor when electric current flows through it*

LS 4.1.3

Effect of a Current-carrying Coil in a Magnetic Field

Figure 4.8 shows a rectangular coil formed with a piece of copper wire. When the coil is connected to a power supply, current can flow through the coil in the direction of $A \rightarrow B \rightarrow C \rightarrow D$ or $D \rightarrow C \rightarrow B \rightarrow A$. What is the effect on the coil if the coil carries a current in a magnetic field?

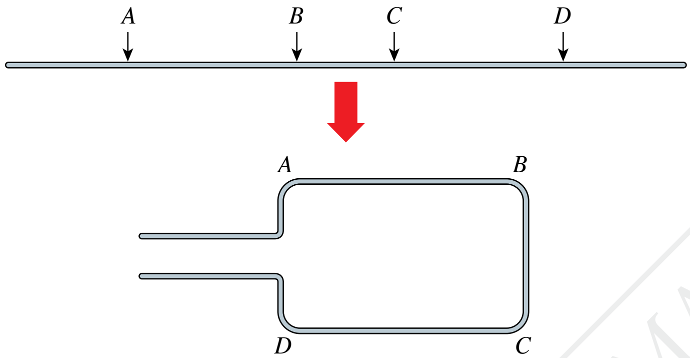


Figure 4.8 *A rectangular coil formed with a copper wire*

Activity 4.4

ISS | ICS

Aim: To observe the turning effect on a current-carrying coil in a magnetic field

Instructions:

1. Carry out this activity in pairs.
2. Scan the given QR code to watch a video on the turning effect on a current-carrying coil in a magnetic field.
3. Download Figure 4.9 from the given website and complete the diagram by:
   (a) labelling the direction of the current in sections *AB*, *BC* and *CD*
   (b) labelling the direction of the force on the coil at sections *AB* and *CD*
   (c) mark the direction of rotation of the coil

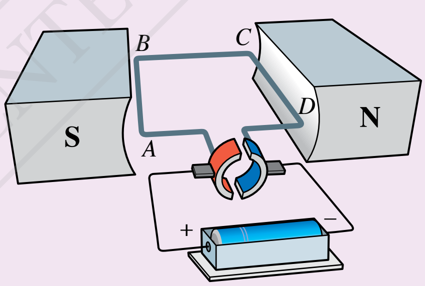


Figure 4.9

SCAN ME
Video of turning effect on a current-carrying coil
http://bit.ly/2YwcXXr

SCAN ME
Worksheet (Figure 4.9)
http://bit.ly/3gqdyAa

The current-carrying coil in a magnetic field will rotate about the axis of rotation. This rotation is due to a pair of forces of equal magnitude but in opposite directions acting on the sides of the coil. This pair of forces is produced by the interaction between the current-carrying coil and the magnetic field from the permanent magnet.

Figure 4.10 shows the pair of forces acting on sides *AB* and *CD* of a current-carrying coil. The interaction between the magnetic field from the current-carrying coil and the magnetic field from the permanent magnet as shown in Figure 4.11 produces a catapult field as shown in Figure 4.12. The catapult field exerts a force on sides *AB* and *CD* of the coil respectively. This pair of forces rotates the coil. The turning effect on a current-carrying coil in a magnetic field is the working principle of the direct current motor.

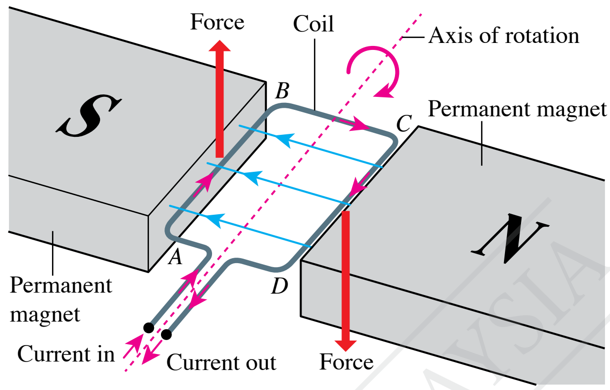


Figure 4.10 *A pair of forces acting in a magnetic field causes the coil to rotate*

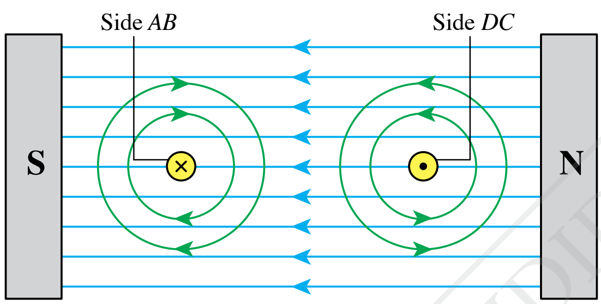


Figure 4.11 *Direction of magnetic field around sides AB and CD*

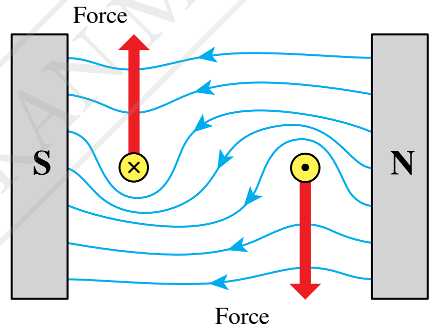


Figure 4.12 *Catapult fields is produced*

Direct Current Motor

Small electrical appliances such as children's toys, portable drills and the hard disk of a computer have a small direct current motor. Larger direct current motors are found in machines such as electric vehicles, lifts and rollers in factories. The direct current motor changes electrical energy to kinetic energy by using the turning effect of a current-carrying coil in a magnetic field. What is the working principle of a direct current motor?

Activity 4.5

ISS ICS

Aim: To gather information on the working principle of a direct current motor

Instructions:

1. Carry out this activity in pairs.
2. Scan the QR code and watch the video of the working principle of the direct current motor.
3. Refer to other materials to obtain additional information.
4. Prepare a multimedia presentation entitled 'The Working Principle of Direct Current Motors'.

SCAN ME
Video of direct current motor and its working principle
http://bit.ly/2CRxX3c

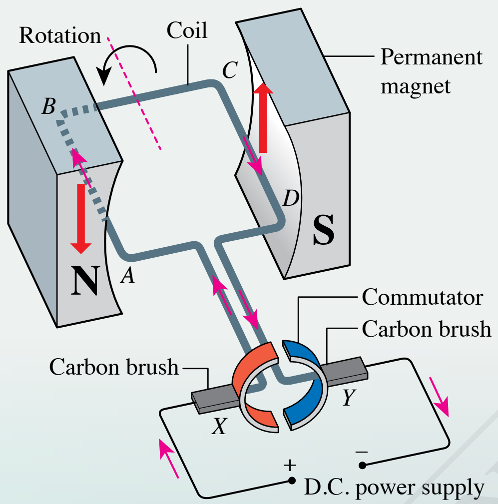
LS 4.1.4 4.1.5

Figure 4.13 shows a direct current motor during the first half of its rotation and the second half of its rotation. An important component in a direct current motor is the commutator that rotates with the rectangular coil. The carbon brushes in contact with the commutator are in their fixed positions.

Brain-Teaser

Why is the commutator not a full ring but a ring split into two halves? Can the commutator be split into more sections?

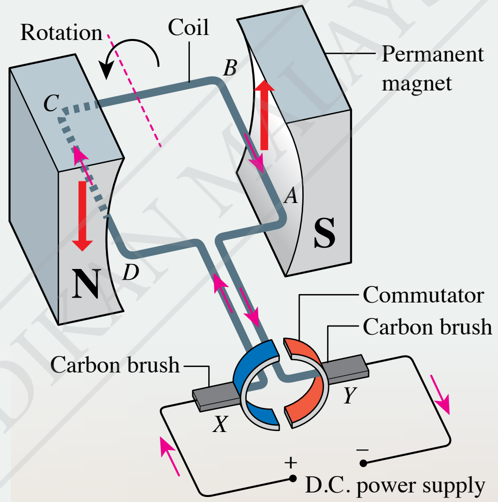
First Half Rotation



First-half rotation
Direction of current in the coil: *ABCD*

- Carbon brush *X* in contact with red half of the commutator
- Carbon brush *Y* in contact with blue half of the commutator
- Direction of current in the coil $A \rightarrow B \rightarrow C \rightarrow D$
- Side *AB* of the coil: force acts downwards
  Side *CD* of the coil: force acts upwards
- Coil rotates in one direction

Second Half Rotation



Second-half rotation
Direction of current in the coil: *DCBA*

- Carbon brush *X* in contact with blue half of the commutator
- Carbon brush *Y* in contact with red half of the commutator
- Direction of current in the coil $D \rightarrow C \rightarrow B \rightarrow A$
- Side *AB* of the coil: force acts upwards
  Side *CD* of the coil: force acts downwards
- Coil rotates in the same direction as the first half rotation

***Figure 4.13** Working principle of a direct current motor*

Factors Affecting the Speed of Rotation of an Electric Motor

Photograph 4.2 shows a portable device that can function as a screwdriver or a drill. The direct current motor in the device rotates at a low speed when turning a screw. A high speed is necessary when the device is used to drill a hole in the wall. What are the factors that affect the speed of rotation of an electric motor?

Photograph 4.2
Screwdriver and drill

Activity 4.6

Aim: To study the factors that affect the speed of rotation of an electric motor

Apparatus: Direct current power supply and a pair of Magnadur magnets

Materials: Insulated copper wire (s.w.g. 26), two large paper clips, two pieces of thumb tacks and connecting wires

Instructions:

1. Set up the arrangement of apparatus as shown in Figure 4.14.

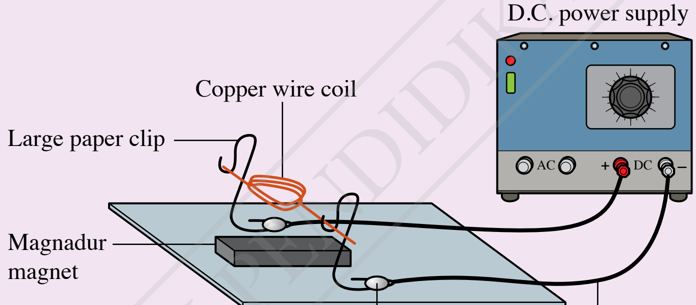


Figure 4.14

2. Adjust the voltage of the power supply to 4.0 V. Turn on the power supply and observe the speed of rotation of the motor.
3. Repeat step 2 using a voltage of 6.0 V.
4. Add one more Magnadur magnet to produce a stronger magnetic field. Turn on the power supply and observe the speed of rotation of the motor.
5. Add more turns to the copper coil. Turn on the power supply and observe the speed of rotation of the motor.

Safety Precaution

- Switch off the power supply immediately after an observation has been made.
- Current should flow for only a short time so that the coil will not become too hot.

Discussion:

1. What is the relationship between the current in the coil and the voltage supplied?
2. Describe the change in the speed of rotation of the motor when:
   (a) the voltage supplied is increased
   (b) the strength of the magnetic field is increased
   (c) the number of turns of the coil is increased
3. State the factors that affect the speed of rotation of a motor.

Activity 4.6 shows that the speed of rotation of an electric motor increases when:

Current in the coil increases	Strength of magnetic field increases	Coil with more turns is used

Activity 4.7

CPS / ICS

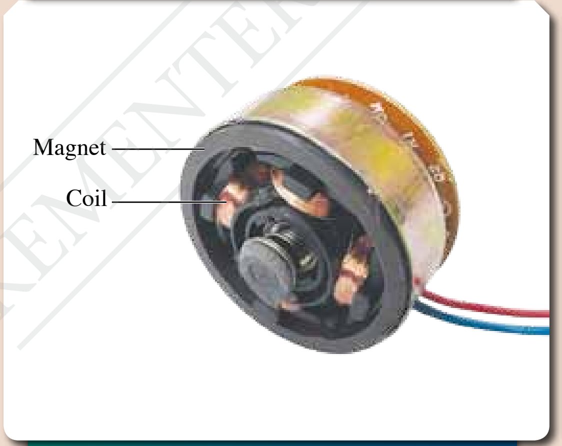
Aim: To study the direct current motors found in used devices to identify the arrangement of the coil and the commutator

Instructions:

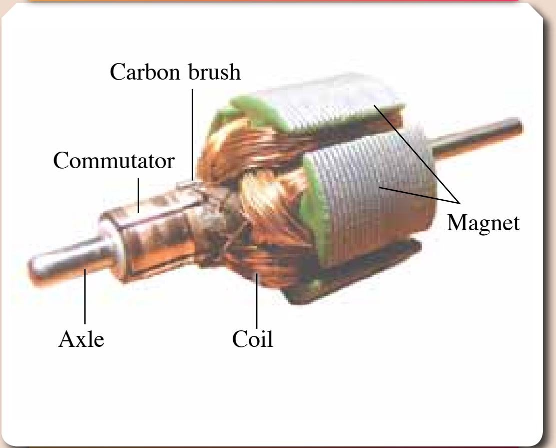
1. Collect a few direct current electric motors from used devices.
2. With the aid and guidance of your teacher, dismantle each motor and identify the coil, the magnet and the commutator.
3. Observe the position of the coil and the magnet in the motor.
4. Observe also the number of sections in the commutator.
5. Prepare a brief report that compares and contrasts the arrangement of the coil, magnet and commutator in direct current motors.

While carrying out Activity 4.7, you may have come across electric motors which do not have a commutator and carbon brushes. Photograph 4.3 shows a brushless motor and a brushed motor. What is the advantage of brushless motors?

Brushless Motor



Brushed Motor



Photograph 4.3 *Brushless motor and brushed motor*

Activity 4.8

ICS

Aim: To study and report on the advantages of brushless motor compared to brushed motor

Instructions:

1. Carry out a Three Stray, One Stay activity.
2. Scan the QR code given or refer to other reference materials to:
   (a) understand the working principle of brushless motor
   (b) study the advantages of brushless motor compared to brushed motor
3. Report the findings of your study.

SCAN ME
Differences between brushless motor and brushed motor
http://bit.ly/2YwZUBi

Table 4.2 shows the comparison between brushless motor and brushed motor.

Table 4.2 *Comparison between brushless motor and brushed motor*

Brushless motor	Brushed motor
Similarities	
Has a magnet and a coil	
Uses magnetic force to produce rotation	
Differences	
Coil is stationary, magnet rotates	Magnet is stationary, coil rotates
No carbon brushes, therefore no friction between the brushes and the commutator	Friction between the carbon brush and the commutator causes the carbon brush to wear out
No sparking at the commutator	Sparking at the commutator
Soft operational sound	Louder operational noise

Activity 4.9

STEM CPS ICS

Aim: To design a simple and efficient homopolar motor

Materials: Neodymium magnet, AA dry cell and copper wire (s.w.g. 18 to 22)

Instructions:

1. Carry out this activity in groups.
2. Gather information on homopolar motors from the aspect of:
   (a) the working principle of homopolar motors
   (b) the shape and size of the neodymium magnet
   (c) various designs of the copper wire that can be tried out
3. Use the K-W-L Data Strategy Form.

SCAN ME
K-W-L Data Strategy Form
http://bit.ly/301Sucu

4. Sketch the design of a homopolar motor.
5. Construct the homopolar motor according to the suggested design.
6. Operate the homopolar motor that you have constructed.
7. Observe the rotation produced and identify the aspects of the design that need to be improved.
8. Discuss the steps of improvement that can be carried out.
9. Improve the homopolar motor if necessary and test the rotation.
10. Based on your experience in designing and constructing the homopolar motor, discuss ways to construct a more efficient motor at a low cost.
11. Present the outcome.

EAC History

In the year 1821, Michael Faraday constructed and demonstrated the operation of a homopolar motor at the Royal Institute, London.

Formative Practice 4.1

1. With the aid of a labelled diagram, explain the meaning of catapult field.
2. Figure 4.15 shows the arrangement of apparatus to study the effect of a force on a current-carrying conductor.

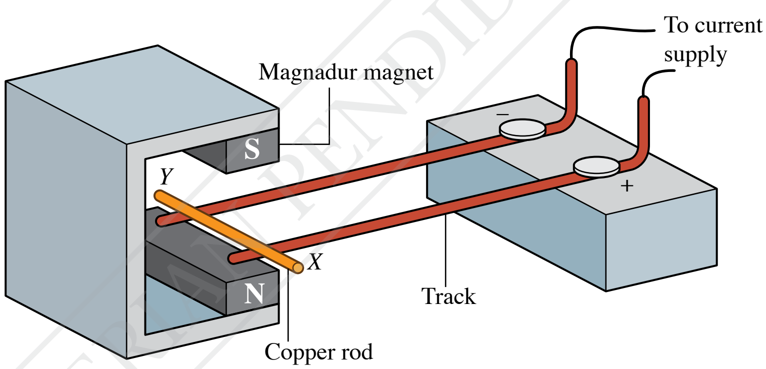


Figure 4.15

(a) What is the direction of the current in the copper wire *XY* when the switch of the direct current power supply is turned on?
(b) Explain the motion of the copper wire *XY* and state the direction of the motion.

3. State three factors that affect the speed of rotation of a motor.
4. (a) Compare and contrast the structure of a brushed motor with a brushless motor.
(b) State two advantages of brushless motor compared to brushed motor.

4.2 Electromagnetic Induction

Photograph 4.4 shows a musician plucking an electric bass guitar. The guitar pickup consisting of four magnets and copper coils produces an electric signal by electromagnetic induction. How does electromagnetic induction produce an electric current without the use of dry cells?

***Photograph 4.4** Components in an electric bass guitar pickup*

Activity 4.10

Aim: To study electromagnetic induction in a straight wire and a solenoid

A Straight wire

Apparatus: A pair of Magnadur magnets, copper rod and sensitive centre-zero galvanometer or digital multimeter

Material: Connecting wires with crocodile clips

Instructions:

1. Set up the apparatus as shown in Figure 4.16.

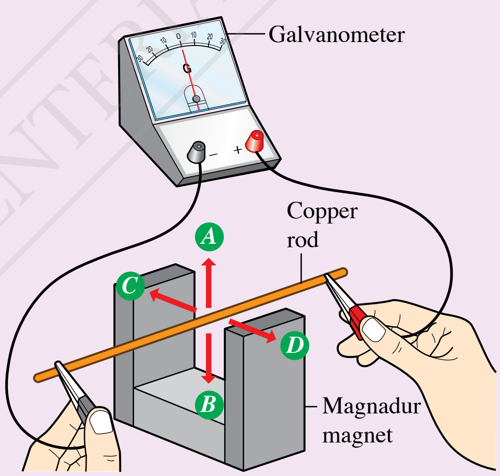
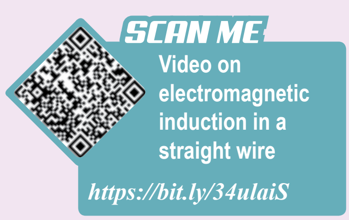


Figure 4.16



2. Hold the copper rod stationary between the poles of the magnet as shown in Figure 4.16. Observe the reading of the galvanometer.

3. Move the copper rod quickly in direction *A* as shown in Figure 4.16. Observe the deflection of the galvanometer pointer.
4. Repeat step 3 in directions *B*, *C* and *D*.
5. Hold the copper rod with your left hand. Lift up the Magnadur magnet with your right hand. Move the Magnadur magnet in direction *A* and direction *B* with the copper rod stationary in between the poles of the magnet. Observe the deflection of the galvanometer pointer.
6. Complete Table 4.3 with a tick (✓) for the direction of deflection of the pointer of the galvanometer.

Results:

Table 4.3

State of Magnadur magnet	State of copper rod	Deflection of galvanometer pointer		
		To the left [–]	Zero [0]	To the right [+]
Stationary	Stationary			
Stationary	Moves in direction *A*			
Stationary	Moves in direction *B*			
Stationary	Moves in direction *C*			
Stationary	Moves in direction *D*			
Moves in direction *A*	Stationary			
Moves in direction *B*	Stationary			

Discussion:

1. What causes the deflection of the galvanometer pointer?
2. State the direction of the magnetic field between the poles of the magnet.
3. What are the directions of motion of the copper rod that causes the cutting of magnetic field lines?
4. Explain the condition where a current is produced in the copper rod.

B Solenoid

Apparatus: Bar magnet, solenoid (at least 400 turns) and sensitive centre-zero galvanometer or digital multimeter

Material: Connecting wires with crocodile clips

Instructions:

1. Set up the arrangement of apparatus as shown in Figure 4.17.
2. Hold the bar magnet stationary near the solenoid as shown in Figure 4.17. Observe the reading of the galvanometer.
3. Push the bar magnet into the solenoid. Observe the deflection of the galvanometer pointer.
4. Hold the bar magnet stationary in the solenoid. Observe the reading of the galvanometer.
5. Pull the bar magnet out of the solenoid. Observe the deflection of the galvanometer pointer.
6. Hold the magnet stationary. Move the solenoid towards and away from the bar magnet. Observe the deflection of the galvanometer pointer.
7. Complete Table 4.4 with a tick (✓) for the direction of deflection of the galvanometer pointer.

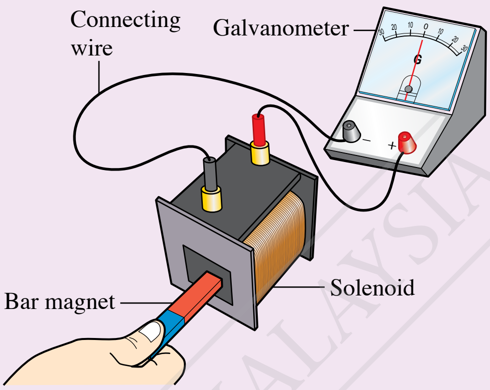


Figure 4.17

Results:

Table 4.4

State of bar magnet	State of solenoid	Deflection of galvanometer pointer		
		To the left [–]	Zero [0]	To the right [+]
Stationary	Stationary			
Moves into the solenoid	Stationary			
Moves out of the solenoid	Stationary			
Stationary	Moves towards the bar magnet			
Stationary	Moves away from the bar magnet			

Discussion:

1. What do you observe about the deflection of the galvanometer pointer when:
   (a) the bar magnet is moved towards the solenoid?
   (b) the bar magnet is moved away from the solenoid?
2. State the condition where a current is produced in the solenoid.

When a piece of copper wire is moved across magnetic flux, an electromotive force (e.m.f.) is induced in the wire. This phenomenon is known as **electromagnetic induction**. If the wire is connected to form a complete circuit, a deflection of the galvanometer pointer is observed as shown in Figure 4.18. This shows that induced current is produced. An electromotive force is also induced in the wire if the magnet is moved towards the stationary wire as shown in Figure 4.19.

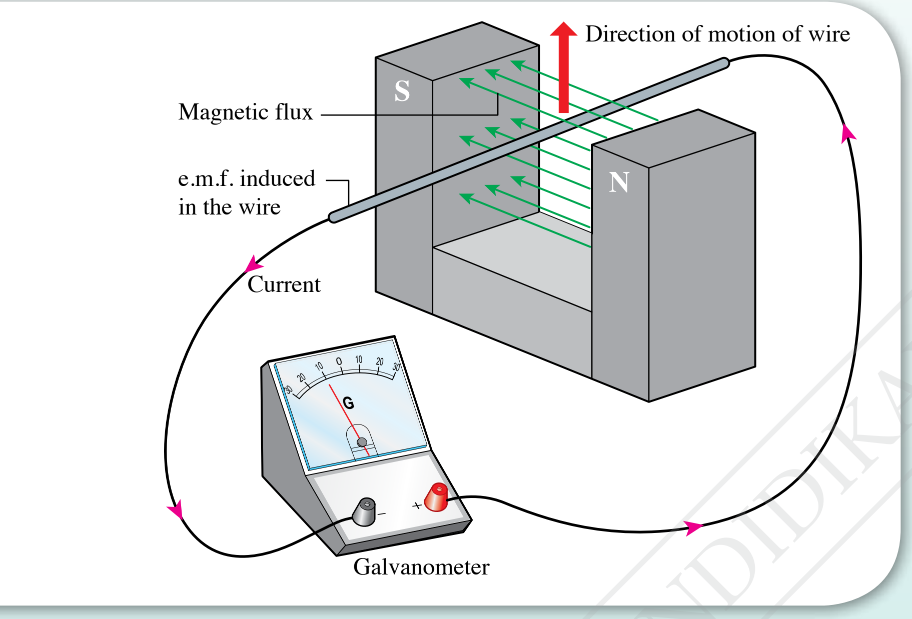
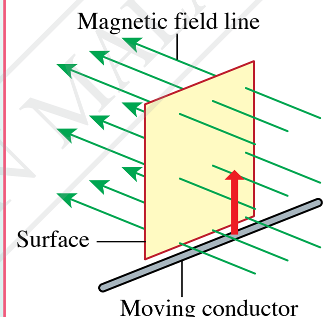


***Figure 4.18** Magnets are stationary while conductor is moved*

Info GALLERY

Magnetic flux refers to magnetic field lines that pass through a surface.



A conductor that moves and cuts magnetic field lines can be said to cut magnetic flux.

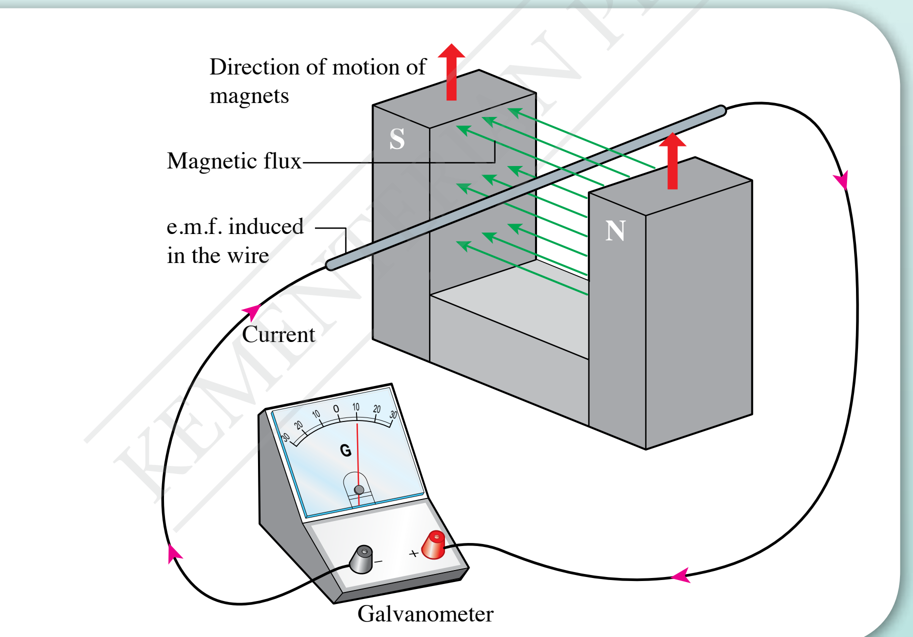


***Figure 4.19** Magnets are moved while conductor is stationary*

AR

SCAN ME
Video of electromagnetic induction for a copper wire
http://bit.ly/34t4c47

LS 4.2.1

When a bar magnet is moved towards or away from a solenoid, the turns of the solenoid cut the magnetic field lines. Electromagnetic induction occurs and an e.m.f. is induced across the solenoid as shown in Figure 4.20.

Figure 4.21 shows the ends of the solenoid are connected to a galvanometer to form a complete circuit. The induced electromotive force will produce an induced current in the circuit and the galvanometer pointer shows a deflection.

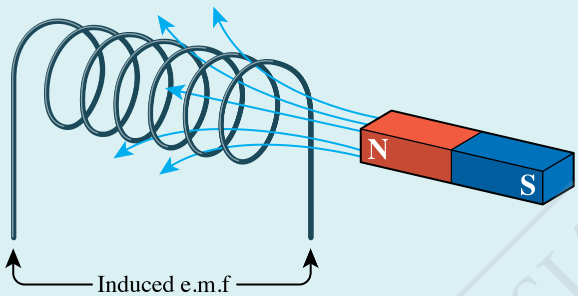


Figure 4.20 *Magnetic field lines are cut by the solenoid and e.m.f. is induced*

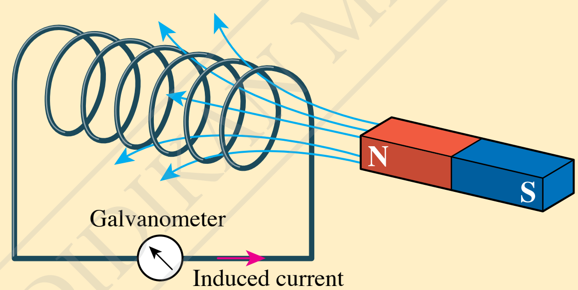


Figure 4.21 *Induced current in a complete circuit*

Activity 4.10 shows that an induced e.m.f. is produced by the cutting of magnetic field lines when a magnet and a conductor move towards or away from each other. **Electromagnetic induction** is the **production of an induced e.m.f. in a conductor when there is relative motion between the conductor and a magnetic field or when the conductor is in a changing magnetic field**.

Info GALLERY

Relative motion between two objects is the motion that results in the two objects becoming closer to each other or further away from each other.

$\boxed{A}$ $\boxed{B}$

Relative motion occurs between objects *A* and *B* if:
- object *A* is stationary and object *B* moves towards or away from *A*
- object *B* is stationary and object *A* moves towards or away from *B*
- both objects *A* and *B* move with different velocities

No relative motion between objects *A* and *B* if:
- both objects *A* and *B* are stationary
- both objects *A* and *B* move with the same speed in the same direction

Factors Affecting the Magnitude of the Induced e.m.f.

Figure 4.22 shows an induction lamp made by a pupil. He found that the LED lights up with different brightness when the magnet in the PVC pipe is shaken at different speeds. What are the factors that affect the magnitude of induced e.m.f.?

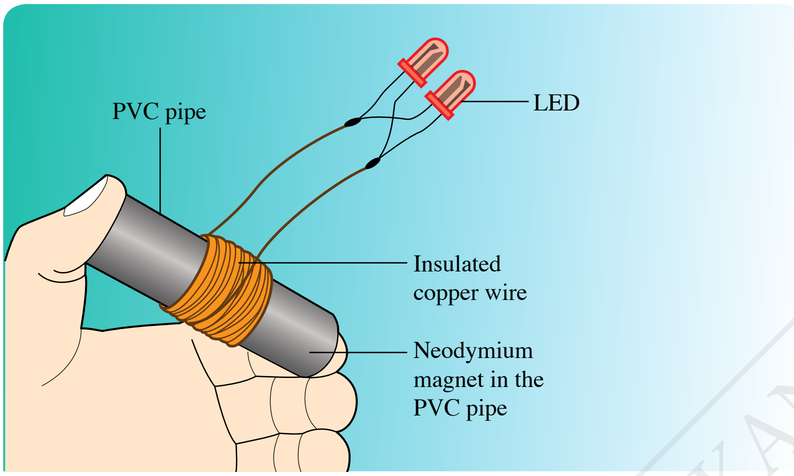


Figure 4.22 *A self-made induction lamp*

Let's Try

Construction of an induction lamp

http://bit.ly/36hR3IU

http://bit.ly/2Yyqq0V

Activity 4.11

Aim: To study the factors affecting the magnitude of induced e.m.f.

Apparatus: Two solenoids with 400 and 800 turns respectively, two bar magnets and sensitive centre-zero galvanometer

Materials: Connecting wires and rubber band

Instructions:

1. Set up the apparatus as shown in Figure 4.23.
2. Push a bar magnet slowly into the solenoid with 400 turns. Record the maximum reading shown on the galvanometer.
3. Push the bar magnet quickly into the solenoid with 400 turns. Record the maximum reading shown on the galvanometer.
4. Push a bar magnet slowly into a solenoid with 800 turns. Record the maximum reading shown on the galvanometer.
5. Use a rubber band to tie two bar magnets together with like poles side by side.
6. Push the two bar magnets slowly into the solenoid with 800 turns. Record the maximum reading shown on the galvanometer in Table 4.5.

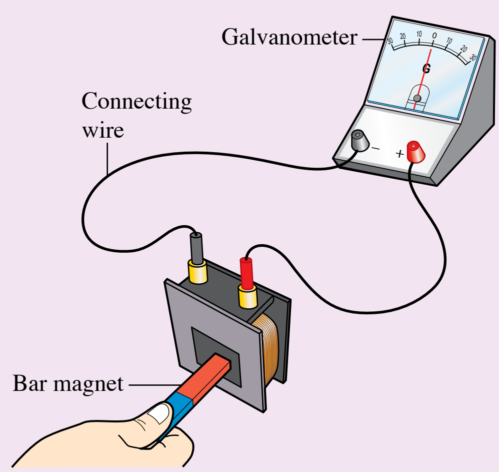


Figure 4.23

Results:

Table 4.5

Number of magnets	Speed of magnet	Number of turns of solenoid	Maximum reading of galvanometer		
			First attempt	Second attempt	Average
One	Slow	400			
One	Fast	400			
One	Slow	800			
Two	Slow	800			

Discussion:

1. Why does the galvanometer pointer deflect when a magnet is pushed into the solenoid?
2. Which factor is studied when the bar magnet is pushed at different speeds into the solenoid?
3. Which factor is studied when the number of magnets pushed into the solenoid is different?
4. How is the magnitude of induced e.m.f. affected by:
   (a) the speed of magnet?
   (b) the number of turns of solenoid?
   (c) the strength of magnetic field?

The results of Activity 4.11 show that the magnitude of induced e.m.f. is affected by the speed of relative motion between the magnet and the conductor, the number of turns of the solenoid and the strength of the magnetic field.

For the relative motion of a straight wire and magnet, the induced e.m.f. increases when:

- the speed of relative motion increases
- the strength of the magnetic field increases

For the relative motion of a solenoid and magnet, the induced e.m.f. increases when:

- the speed of relative motion increases
- the number of turns of the solenoid increases
- the strength of the magnetic field increases

EAL History

Michael Faraday (1791-1867) discovered electromagnetic induction in the year 1831. He successfully constructed an electric dynamo. The electric dynamo was used to generate electrical power.

The magnitude of the e.m.f. increases if more magnetic field lines are cut in a certain period of time. **Faraday's law** **states that the magnitude of induced e.m.f. is directly proportional to the rate of cutting of magnetic flux**.

Direction of Induced Current in a Straight Wire and Solenoid

You have observed that the direction of the induced current changes when there is a change in the direction of the relative motion between the conductor and the magnet in Activity 4.10. Carry out Activity 4.12 and 4.13 to study the direction of the induced current in a straight wire and solenoid.

SCAN ME
To determine the direction of current using a galvanometer
https://bit.ly/3lhdUMY

Activity 4.12

Aim: To study the direction of the induced current in a straight wire

Apparatus: Thick copper wire, a pair of Magnadur magnets, sensitive centre-zero galvanometer or digital multimeter, a dry cell with holder, 1 kΩ resistor and switch

Material: Connecting wires with crocodile clips

SCAN ME
Video on ways to use multimeter
https://bit.ly/3gqj3Pa

Instructions:

1. Set up the apparatus as shown in Figure 4.24.

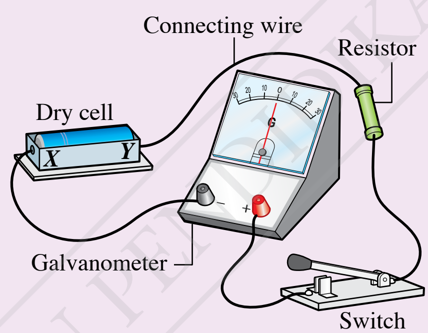


Figure 4.24

2. Connect the dry cell with its positive terminal at Y and negative terminal at X.
3. Turn on the switch. Observe the direction of deflection of the galvanometer pointer (to the left or to the right) and record your observation in Table 4.6. Determine the direction of the current through the dry cell (X to Y or Y to X).
4. Reverse the dry cell so that the positive terminal is at X and negative terminal at Y and repeat step 3.
5. Remove the dry cell from the circuit and replace with a piece of thick copper wire. Place the thick copper wire between the pair of Magnadur magnets as shown in Figure 4.25.
6. Move the copper wire upwards (direction A). Observe and record the direction of deflection of the galvanometer pointer and the direction of the current through the copper wire in Table 4.6.
7. Repeat step 6 by moving the copper wire downwards (direction B).

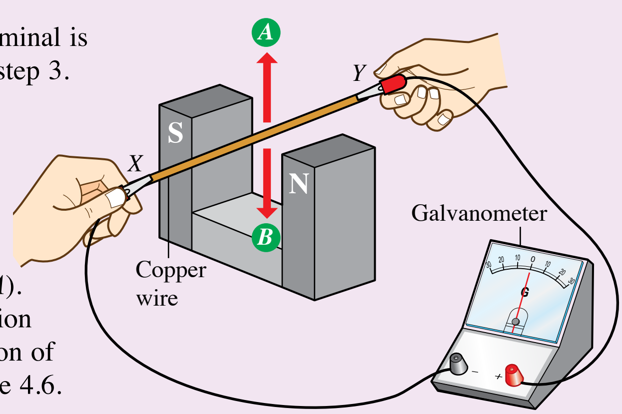


Figure 4.25

Results:

Table 4.6

Situation	Direction of deflection of galvanometer pointer (to the left or to the right)	Direction of current (X to Y or Y to X)
Dry cell (positive terminal at Y, negative terminal at X)		
Dry cell reversed (negative terminal at Y, positive terminal at X)		
Copper wire moved upwards (direction A)		
Copper wire moved downwards (direction B)		

Discussion:

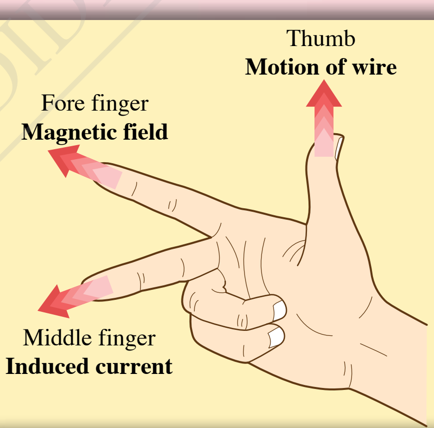
1. Try to relate the direction of the magnetic field lines, direction of motion of the copper wire and direction of the induced current by using the Fleming's right-hand rule.
2. Suggest other ways to change the direction of the induced current other than the direction of motion of the copper wire.

Fleming's right-hand rule

The direction of the induced current in a straight wire can be determined by using Fleming's right-hand rule as shown in Figure 4.26.

BRIGHT Info

The motion of the magnet downwards is equivalent to the motion of the wire upwards.



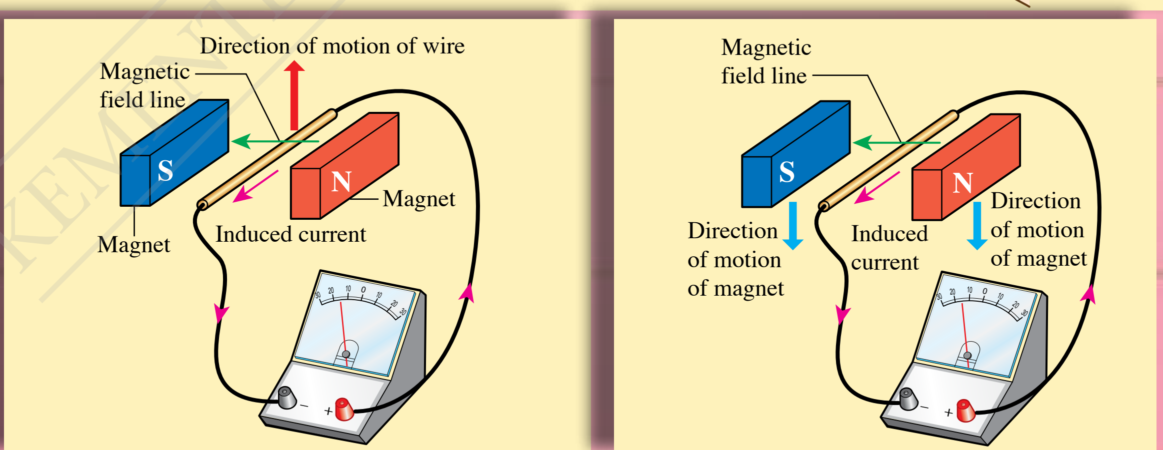


Figure 4.26 *Fleming's right-hand rule to determine the direction of induced current for straight wire*

LS 4.2.3

Activity 4.13

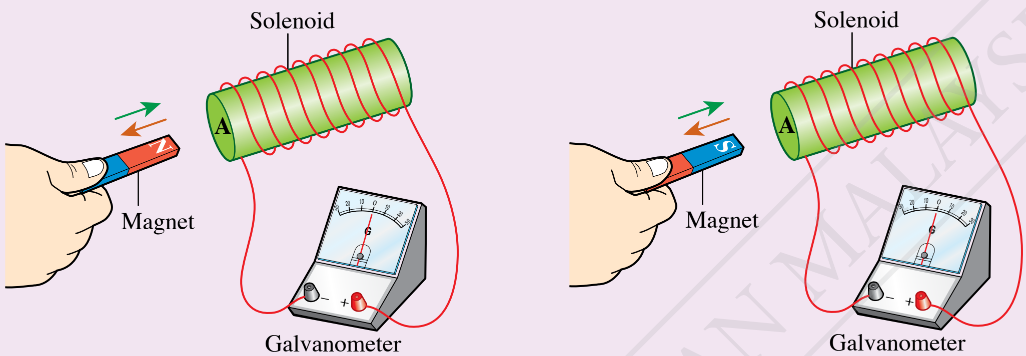
Aim: To study the direction of the induced current in a solenoid

Apparatus: Solenoid, bar magnet and sensitive centre-zero galvanometer or digital multimeter

Material: Connecting wires with crocodile clips

Instructions:

1. Set up the apparatus as shown in Figure 4.27.



(a) *(b)*

Figure 4.27

2. Move the north pole of the bar magnet as shown in Figure 4.27(a):
   (a) towards end *A* of the solenoid
   (b) away from end *A* of the solenoid
3. Observe the deflection of the galvanometer pointer and determine the polarity of the magnetic field at end *A* of the solenoid. Scan the QR code for the guideline on determination of the polarity at a solenoid.
4. Move the south pole of the bar magnet as shown in Figure 4.27(b):
   (a) towards end *A* of the solenoid
   (b) away from end *A* of the solenoid
5. Observe the deflection of the galvanometer pointer and determine the polarity of the magnetic field at end *A* of the solenoid.
6. Record your observations and results in Table 4.7.

Let's Recall

Magnetic field produced by current in a solenoid

http://bit.ly/3lfvroV

Results:

Table 4.7

Polarity of bar magnet	Motion of bar magnet at end *A* of the solenoid	Direction of deflection of galvanometer pointer (to the left or to the right)	Magnetic polarity at end *A* of the solenoid (north or south)
North	Towards		
	Away from		
South	Towards		
	Away from		

Discussion:

1. What is the effect of the motion of the bar magnet on the polarity of the magnet at end *A* of the solenoid?
2. Predict the polarity of the magnet produced at end *A*:
   (a) when the south pole of the bar magnet is pushed towards it
   (b) when the south pole of the bar magnet is pulled away from it

Note
Induced current is produced in the solenoid by the relative motion between the bar magnet and the solenoid.

For a solenoid, Lenz's law is used to determine the magnetic polarity at the end of the solenoid when current is induced. **Lenz's law states that the induced current always flows in a direction that opposes the change of magnetic flux that causes it**. Figure 4.28 shows that Lenz's law is used to determine the direction of induced current in a solenoid.

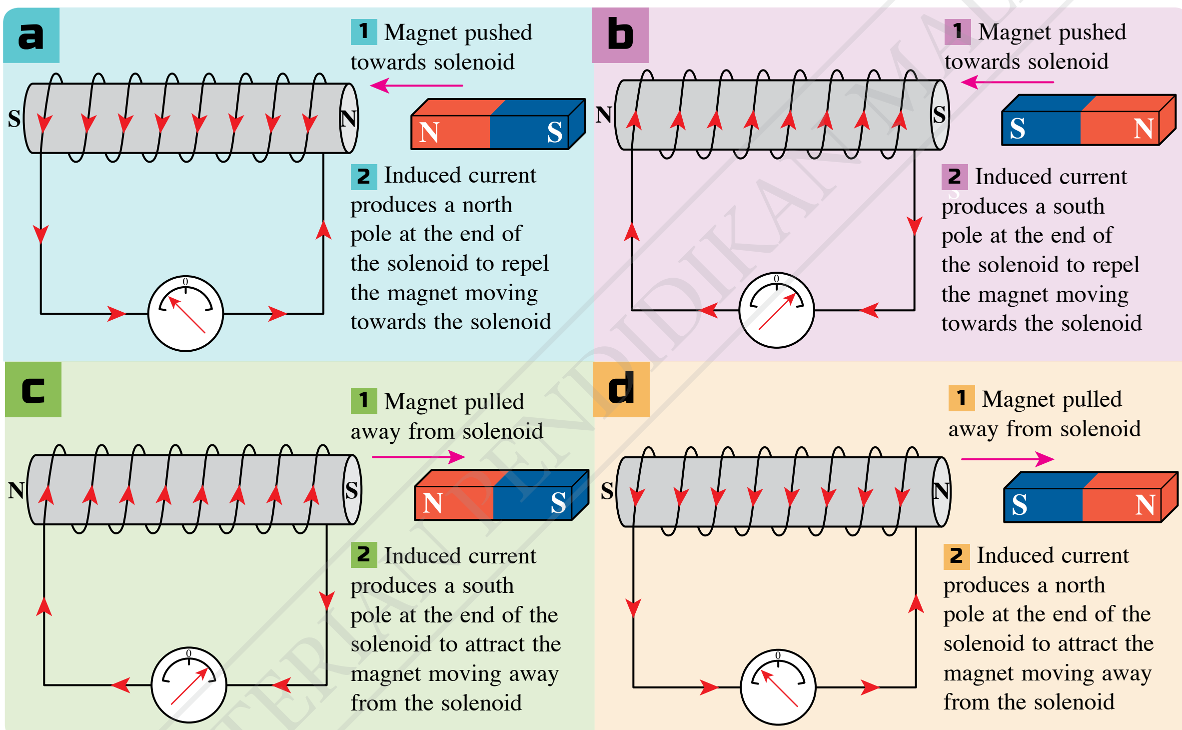


Figure 4.28 *Lenz's law used to determine the direction of induced current in a solenoid*

Direct Current Generator and Alternating Current Generator

Photograph 4.5 shows wind turbines electric generators that apply electromagnetic induction to produce induced e.m.f. There are two types of generators – the direct current generator and alternating current generator. What is the working principle of these current generators?

Photograph 4.5 *Wind turbines at Kuala Perlis*

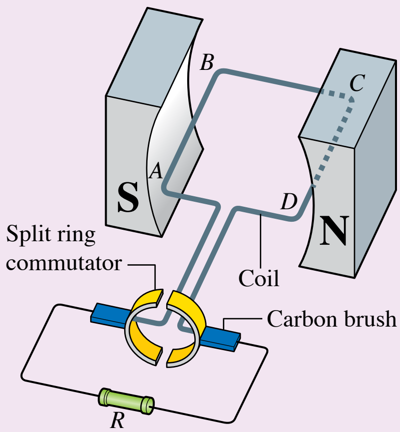
Activity 4.14

ISS / ICS

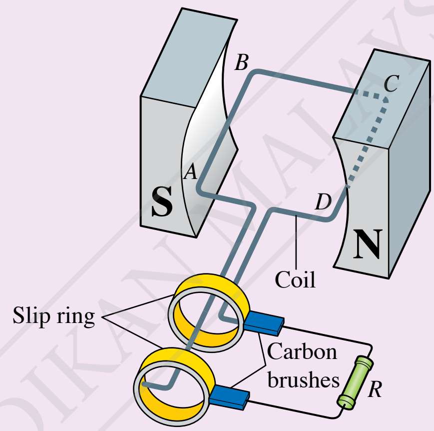
Aim: To gather information on the structure and working principle of the direct current generator and alternating current generator

Instructions:

1. Carry out this activity in groups.
2. Examine Figure 4.29 that shows the structure of the direct current generator and alternating current generator.



(a) Direct current generator



(b) Alternating current generator

Figure 4.29

3. Surf the Internet to gather more detailed information on the structure and working principle of the direct current generator and alternating current generator.
4. Prepare a multimedia presentation entitled 'Structure and Working Principle of the Direct Current Generator and Alternating Current Generator'.

SCAN ME
Video of direct current generator and alternating current generator
http://bit.ly/3aQATtC

Table 4.8 *Working principle of the direct current generator and alternating current generator*

Direct current generator	Alternating current generator
Similarities	
Applies electromagnetic induction	
Coil is rotated by an external force	
Coil cuts magnetic flux	
e.m.f. is induced in the coil	
Differences	
Ends of the coil are connected to a split ring commutator	Ends of the coil are connected to two slip rings
The two sections of the commutator exchange contact with the carbon brush every half rotation	Slip rings are connected to the same carbon brush
Output is direct current	Output is alternating current

Activity 4.15

STEM CPS ICS

Aim: To construct a functional prototype current generator (dynamo) by modifying an electric motor

Instructions:

1. Carry out this activity in groups.
2. Compare and contrast the structures and working principles of the direct current motor and the direct current generator.
3. Gather and study the following information from reading materials or websites:
   (a) the method of converting a motor to a dynamo
   (b) the ways to produce rotation in a dynamo
4. Based on the information you studied, suggest a design for the prototype dynamo and the way to operate it.
5. Construct the dynamo by modifying electric motor according to the suggested design and test the dynamo.
6. From the results of testing the dynamo, discuss the improvements that need to be made.
7. Make the improvements to the prototype dynamo and test the dynamo again.
8. Present the design of your dynamo.

Note
Use the K-W-L strategy data form

SCAN ME
K-W-L Data Strategy Form
http://bit.ly/301Sucu

Formative Practice 4.2

1. What is the meaning of electromagnetic induction?

2. (a) State Faraday's law.
   (b) Use Faraday's law to explain the effect of the speed of rotation of the coil on the magnitude of the induced e.m.f. in a current generator.

3. Figure 4.30 shows a simple pendulum with a bar magnet as the bob oscillating near a copper ring.
   (a) Explain the production of current in the copper ring when the bar magnet is moving towards the ring.
   (b) At the position of the observer in front of the ring as shown in Figure 4.30, state whether the current in the copper ring is clockwise or anti-clockwise.
   (c) Explain the effect of the current in the copper ring on the motion of the bar magnet.

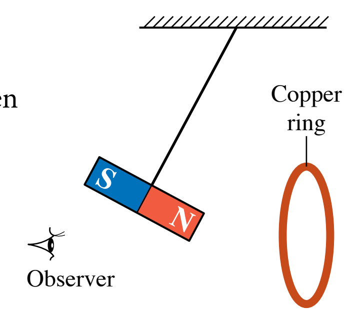


Figure 4.30

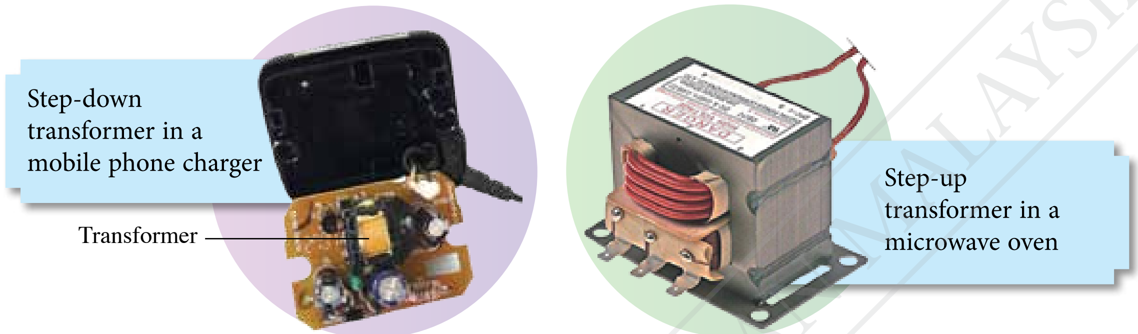
LS 4.2.4

4.3 Transformer

Working Principle of a Simple Transformer

Photograph 4.6 shows a step-up transformer and a step-down transformer that are used in electrical devices. How does a transformer change an input voltage to an output voltage with a different value?

SCAN ME
EduwebTV: Transformer
http://bit.ly/31ppvBD



Photograph 4.6 *Types of transformers used in electrical devices*

Activity 4.16

ISS ICS

Aim: To gather information on the working principle of a simple transformer

Instructions:

1. Carry out this activity in groups.
2. Examine Figure 4.31 that shows the circuit diagram for a simple transformer.

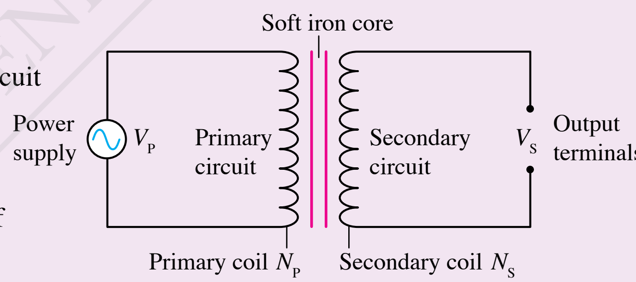


Figure 4.31

3. Surf websites or refer to the Form 3 Science Textbook to search for information on the working principle of the transformer and gather information on the following:
   (a) type of power supply in the primary circuit
   (b) type of current in the primary circuit
   (c) magnetic field produced by the current in the primary coil
   (d) function of the soft iron core
   (e) the phenomenon of electromagnetic induction in the secondary coil
   (f) the magnitude of the voltage induced across the secondary coil
   (g) relationship between V_P, V_S, N_P and N_S, where
   V_P = voltage across the primary coil or input voltage
   V_S = voltage across the secondary coil or output voltage
   N_P = number of turns of the primary coil
   N_S = number of turns of the secondary coil
4. Present the findings.

SCAN ME
Transformer
https://fla.st/2P4tXzN

Figure 4.32 shows the structure of a simple transformer and Figure 4.33 shows the flow map for the working principle of a simple transformer.

Brain-Teaser

Why does the transformer not work with a direct current power supply?

BRIGHT Info

Step-down transformer:
$N_S < N_P \Rightarrow V_S < V_P$

Step-up transformer:
$N_S > N_P \Rightarrow V_S > V_P$

SCAN ME

Video on the working principle of a transformer

http://bit.ly/32BBjR1

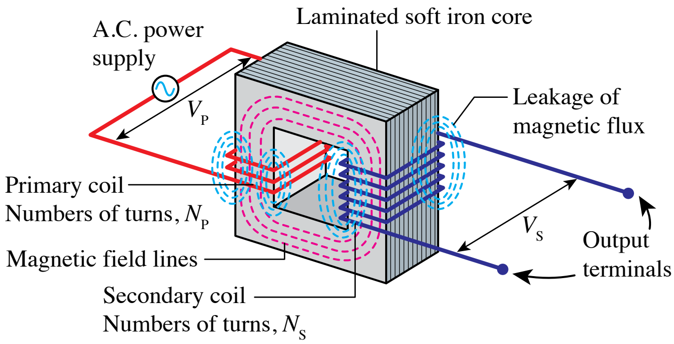


Figure 4.32 *Structure of a simple transformer*

Primary circuit

A.C. power supply produces an alternating current in the primary coil. → The alternating current produces a magnetic field that changes in magnitude and direction. → The magnetic flux from the primary coil is linked to the secondary coil through the soft iron core.

Secondary circuit

The changing magnetic field induces an alternating voltage across the secondary coil. → $\frac{V_s}{V_p} = \frac{N_s}{N_p}$

Figure 4.33 *Working principle of a simple transformer*

Ideal Transformer

Figure 4.34 shows an electrical equipment connected to the output terminals of a transformer. The transformer receives input power from the power supply and supplies the output power to the electrical equipment. Therefore, electrical energy is transferred from the primary circuit to the secondary circuit.

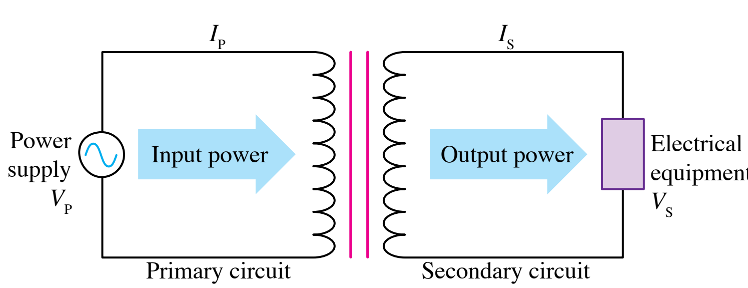


Figure 4.34 *Electrical equipment connected to the output terminals*

LS 4.3.1 4.3.2

A transformer that is in operation experiences a loss of energy. Therefore, the output power is less than the input power. The efficiency of the transformer, η is defined as

$$\eta = \frac{\text{Output power}}{\text{Input power}} \times 100\%$$

SCAN ME
Sample calculation for ideal transformers
http://bit.ly/2FVgecr

Nowadays, there are transformers with very high efficiencies, up to 99%. An **ideal transformer** is a **transformer that does not experience any loss of energy, that is the efficiency, η is 100%.**

For an ideal transformer, efficiency of the transformer, $\eta = \frac{\text{Output power}}{\text{Input power}} \times 100\% = 100\%$

Therefore, output power = input power

$$V_P I_P = V_S I_S$$

Ways to Increase the Efficiency of a Transformer

The working principle of a transformer involves processes such as the flow of current in the copper coils, the change of magnetic field and electromagnetic induction. These processes cause loss of energy and the transformer is unable to operate at an optimum level. Most of the energy is lost in the form of heat energy.

Activity 4.17

ISS ICS

Aim: To gather information and discuss the causes of energy loss in a transformer

Instructions:

1. Examine Table 4.9 that shows four main causes of energy loss and their effects.

Table 4.9

Causes of energy loss	Effects of energy loss
Resistance of coils	• The primary and secondary coils consist of wires that are very long. • When current flows in the coils which have resistance, heating of the wires occurs. • Heating of the wires causes heat energy to be released to the surroundings.
Eddy currents	• The changing magnetic field induces eddy currents in the iron core. • The eddy currents heat up the iron core. • The hot iron core releases heat energy to the surroundings.
Hysteresis	• The iron core is magnetised and demagnetised continuously by the changing magnetic field. • The energy supplied for magnetisation is not fully recovered during demagnetisation. The difference in energy is transferred to the iron core to heat it up.
Leakage of magnetic flux	• The magnetic flux produced by the primary current is not fully linked to the secondary coil.

LS 4.3.2 4.3.3

2. Scan the QR code and print Table 4.9.
3. Discuss the ways to increase the efficiency of transformers and complete Table 4.9.
4. Present the outcome of your discussion in the form of a suitable thinking map.

SCAN ME
Worksheet (Table 4.9)
http://bit.ly/2YvuYVE

The efficiency of a transformer can be increased by reducing the loss of energy in the transformer. Table 4.10 shows ways to reduce the loss of energy in a transformer.

Table 4.10 *Ways to reduce energy loss in a transformer*

Causes of energy loss	Ways to reduce energy loss in a transformer
Resistance of coils	Use thicker copper wire so that the resistance of the coil is smaller.
Eddy currents	Use a laminated iron core that consists of thin iron sheets glued together with insulation glue.
Hysteresis	Use soft iron as the core. Soft iron requires a smaller amount of energy to be magnetised.
Leakage of magnetic flux	The secondary coil is wound on the primary coil so that all the magnetic flux produced by the primary current will pass through the secondary coil.

In the operation of a transformer, eddy currents are a cause of energy loss. However, eddy currents can be beneficial to human beings. Photograph 4.7 shows an induction cooker. Figure 4.35 shows a high-frequency alternating current in the coil producing a magnetic field that changes with a high frequency. This magnetic field induces eddy currents at the base of the pan. The eddy currents heat up the base of the pan.

Photograph 4.7 *Induction cooker*

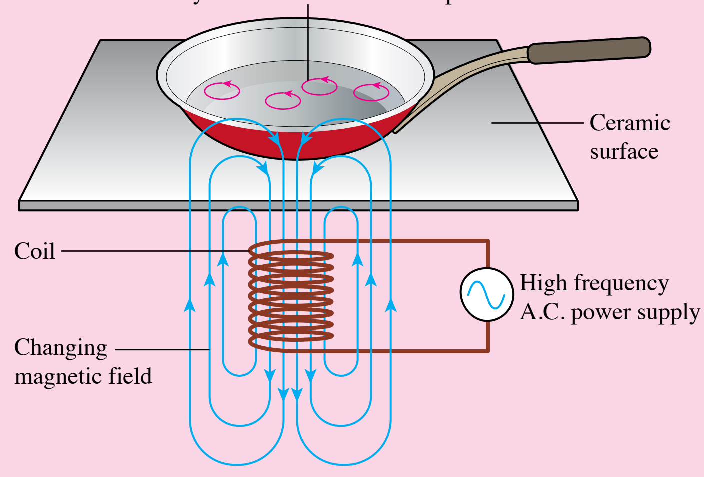


Figure 4.35 *Eddy currents in the induction cooker*

Uses of Transformers in Daily Life

Transformers have a wide range of uses. The following are some examples of machines that use step-down transformers and step-up transformers.

Step-down transformer	Step-up transformer
• Notebook computer charger • Photocopy machine • Welding machine	• Microwave oven • Defibrillator • X-ray machine

Activity 4.18

ISS ICS

Aim: To search for information on the applications of transformers in daily life

Instructions:

1. Carry out a Hot Seat activity.
2. Gather information on the applications of transformers in daily life such as:
   (a) electrical appliances
   (b) electrical energy transmission and distribution systems
3. Information can be obtained from websites or by referring to your Form 3 Science Textbook.
4. Present your findings in the form of a folio.

Example 1

A transformer that is connected to a 240 V power supply supplies 27 W of power at a voltage of 18 V to an electronic equipment, as shown in Figure 4.36. Assuming the transformer is ideal:

(a) calculate the number of turns of the primary coil.
(b) calculate the current in the secondary circuit.
(c) calculate the current in the primary circuit.

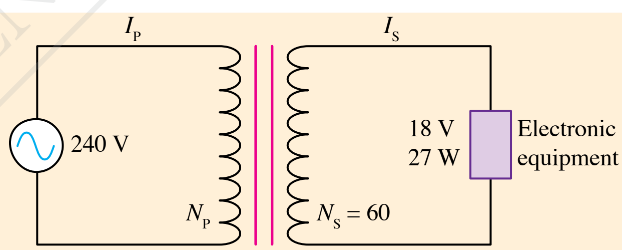


Figure 4.36

Solution

(a) $V_P = 240$ V, $V_S = 18$ V, $N_S = 60$

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

$$\frac{18}{240} = \frac{60}{N_P}$$

$$N_P = \frac{240 \times 60}{18} = 800$$

(b) Output power = 27 W

$$V_S I_S = 27$$

$$18 \times I_S = 27$$

$$I_S = \frac{27}{18}$$

$$= 1.5 \text{ A}$$

(c)

$$V_P I_P = V_S I_S$$

$$240 \times I_P = 18 \times 1.5$$

$$I_P = \frac{18 \times 1.5}{240}$$

$$= 0.1125 \text{ A}$$

Electrical Energy Transmission and Distribution System

Transformers play an important role in the transmission and distribution of electricity from the power station to the consumers. Figure 4.37 shows the use of the step-up transformer and step-down transformer in the system.

SCAN ME
Video of electrical energy transmission and distribution system
http://bit.ly/3jadhmt

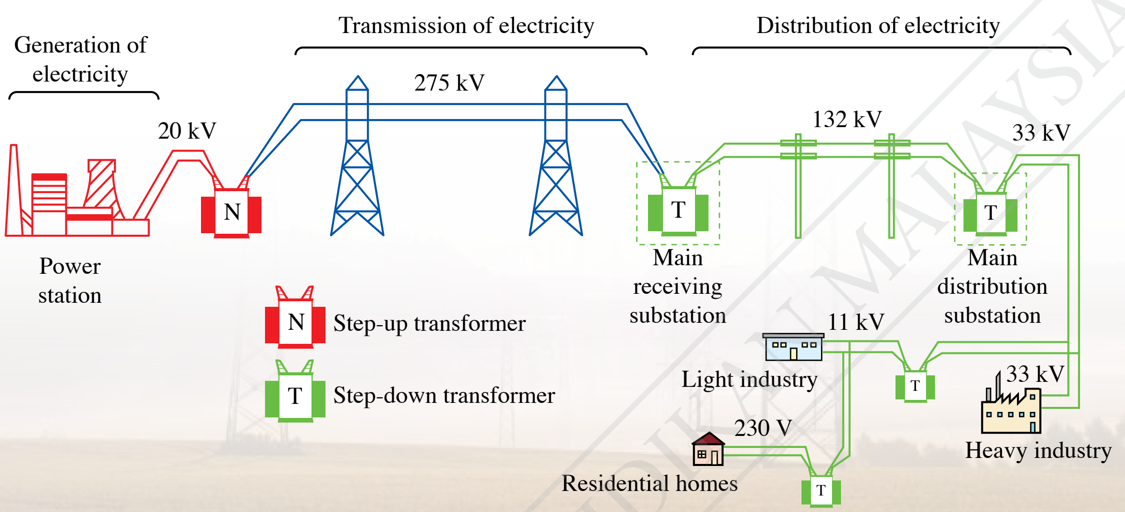


Figure 4.37 *Electrical energy transmission and distribution system from the power station*

At the stage of transmission of electrical energy, step-up transformers are used to increase the voltage in the power cable so that the current in the power cable becomes small. This reduces the loss of electrical energy from the power cable. During the distribution of electrical energy, step-down transformers are used to decrease the voltage in the power cable in stages to a suitable value for industrial and residential consumers.

Formative Practice 4.3

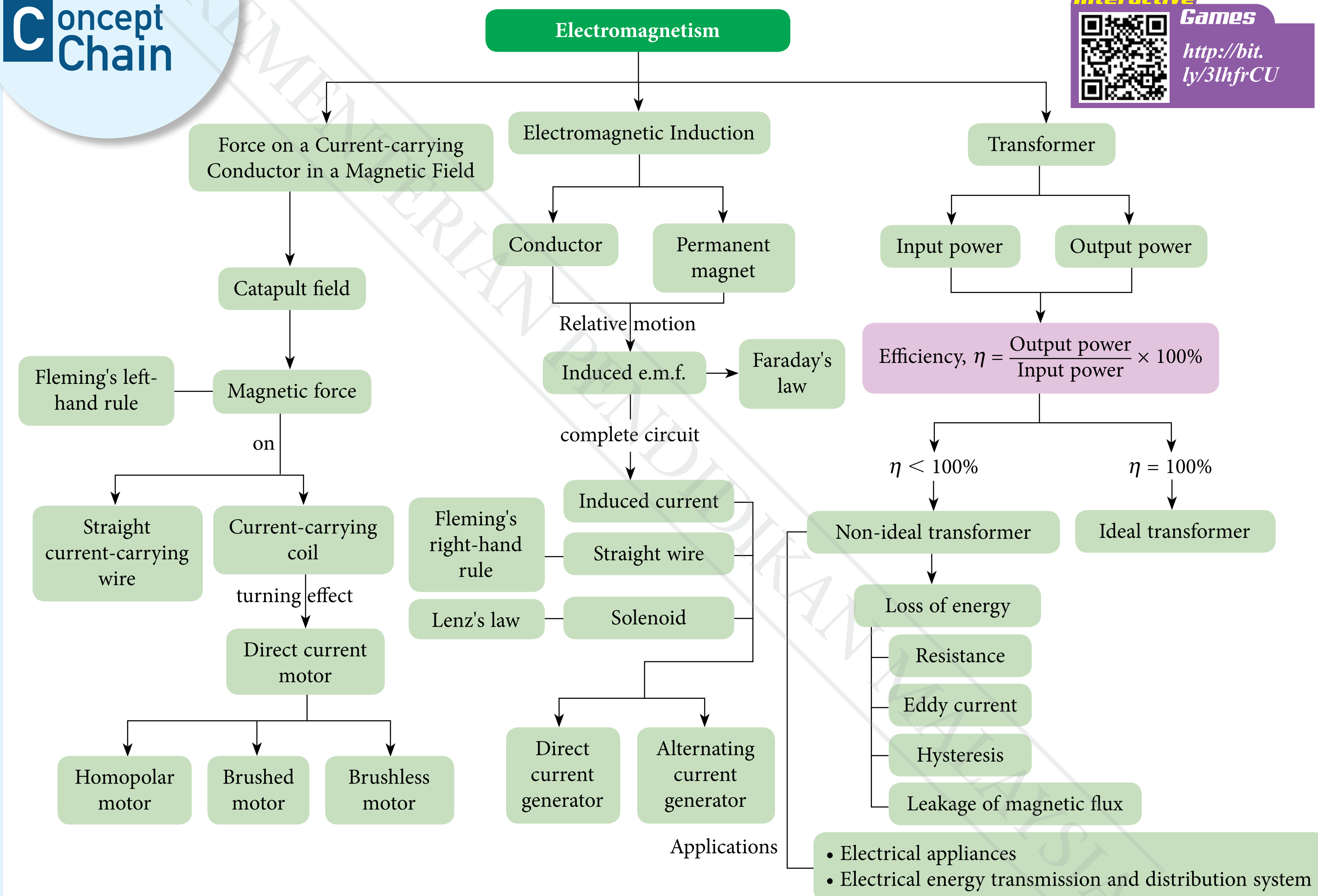
1. A step-down transformer is connected to an alternating current power supply. Explain the working principle of the transformer.
2. A pupil collects the following information on a transformer:

Primary voltage = 120 V	Secondary voltage = 6 V
Primary current = 0.25 A	Secondary current = 4.80 A

   (a) Calculate the efficiency of the transformer.
   (b) Explain two factors that cause the transformer to be non-ideal.
3. Explain how an induction cooker can heat up food in a steel pot.
4. Transformers are used in the electrical energy transmission and distribution system. State the type of transformer used:
   (a) before transmission of electrical energy
   (b) at the distribution substation

Concept Chain

Interactive Games
http://bit.ly/3lhfrCU



Self-Reflection

SCAN ME
Download and print Self-Reflection
http://bit.ly/3lqPDwg

1. New things I have learnt in the chapter 'Electromagnetism' are ______________.
2. The most interesting thing I have learnt this chapter is ______________.
3. The things I still do not fully understand are ______________.
4. My performance in this chapter.
   Poor | 1 | 2 | 3 | 4 | 5 | Very good
5. I need to ______________ to improve my performance in this chapter.

Summative Practice

QUIZ PORTAL
http://bit.ly/3grEJum

1. Figure 1 shows a conductor hanging from a sensitive spring balance in between a pair of Magnadur magnets.

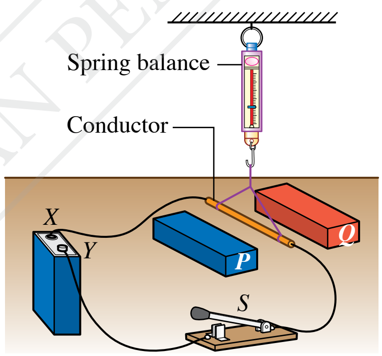


Figure 1

   (a) Suggest the polarity of dry cell X, Y and the polarity of magnets P, Q such that the reading of the spring balance increases when switch S is turned on.
   (b) Explain why the reading of the spring balance can increase in 1(a).
   (c) Suggest improvements that need to be made to further increase the reading of the spring balance.

2. With the aid of a labelled diagram, explain how Fleming's left-hand rule is used to determine the direction of the force on a current-carrying conductor in a magnetic field.

3. Figures 2 and 3 show the induced currents produced when there is relative motion between a bar magnet and a solenoid.

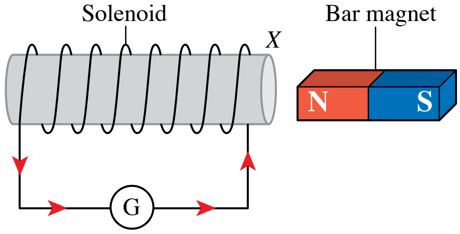


Figure 2

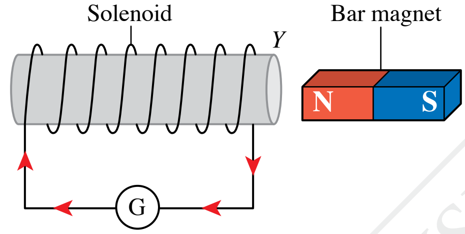


Figure 3

(a) What is the meaning of induced current?

(b) Based on the direction of the current given in Figures 2 and 3, state the magnetic polarities at ends *X* and *Y* of the solenoid.

(c) State the direction of motion of the bar magnet in Figure 2 and Figure 3.

(d) Suggest two ways to increase the magnitude of the induced current in Figure 3.

4. A transformer is used to step down voltage from 240 V to 6 V for an electronic equipment. The current in the primary coil is 0.18 A. What is the current in the secondary coil? State the assumption that needs to be made in your calculation.

5. Figure 4 shows two identical metal balls and a copper tube. One of the balls is a neodymium magnet while the other is a steel ball.

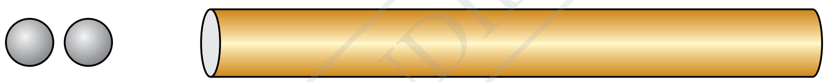


Figure 4

Design an activity that can identify which ball is the neodymium magnet. Explain the physics principle used in your activity.

6. Figure 5 shows a wooden block with a bar magnet tied to it sliding with an acceleration down a smooth track.

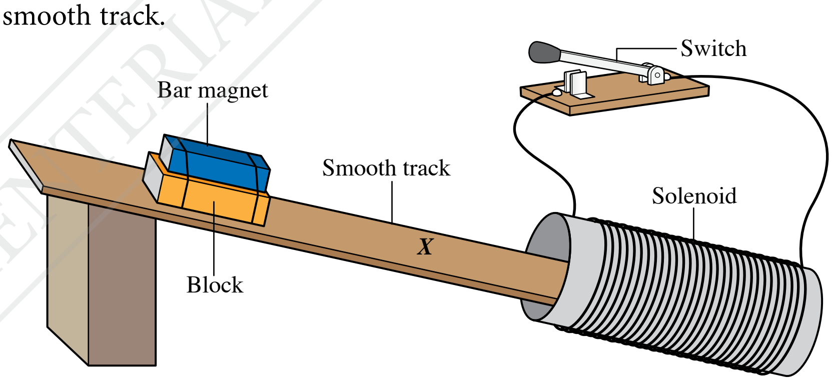


Figure 5

When the block arrives at mark *X* on the track, the switch is turned on.

(a) What is produced in the solenoid? Explain your answer.

(b) Explain the motion of the block after the switch is turned on.

(c) Based on your answers in 6(a) and (b), discuss the effectiveness of electromagnetic braking in stopping a moving object.

7. Figure 6 shows a transformer with a bulb at its output terminals.
(a) Calculate the value of I_S.
(b) What assumption needs to be made in your calculation in 7(a)?

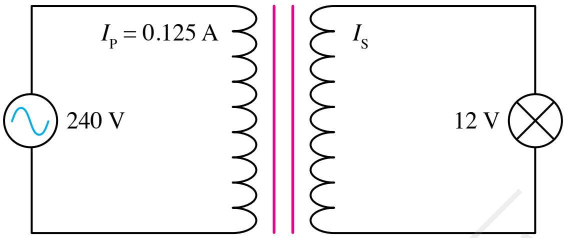


Figure 6

8. A pupil investigated the operation of a transformer and gathered data as shown in Figure 7. Calculate the efficiency of the transformer and suggest improvements to the design of the transformer to increase its efficiency.

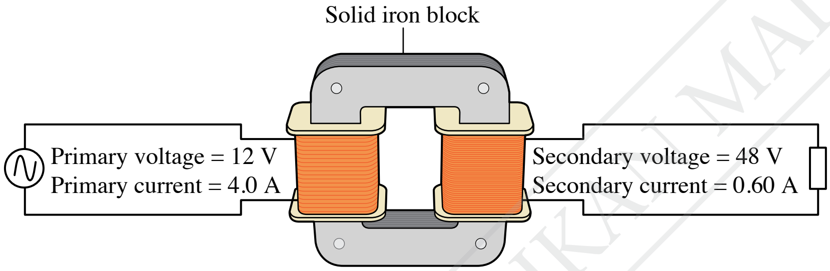


Figure 7

21st Century Challenge

9. Figure 8 shows the design of a simple direct current motor that can produce a force to rotate a disc connected to the axle of the motor. A pupil who constructed the motor according to the design made the following observations:
- speed of rotation of the disc is slow
- speed of rotation of the disc cannot be controlled
- rotation of the disc is not smooth
- the dry cell loses its power in a short time

Study the design of the motor and suggest improvements to the design that can overcome the weaknesses identified by the pupil.

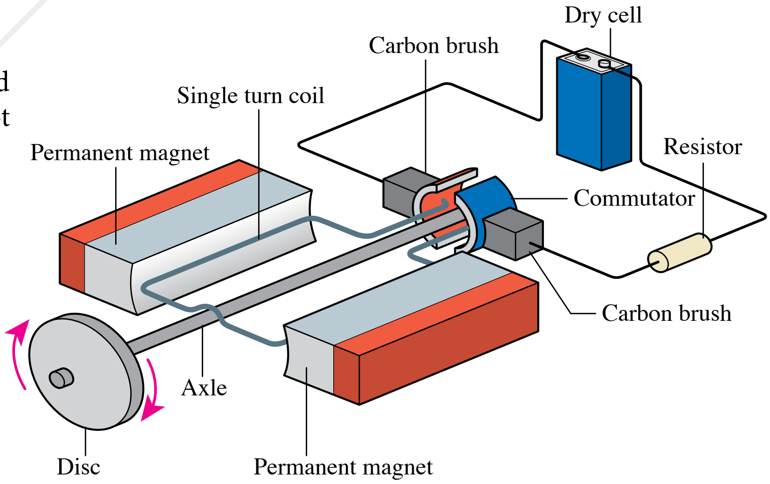


Figure 8