Beatty Secondary School
Secondary 4E Pure Physics
Electromagnetism

Name: __________________________ (   )   Class: __________   Date: _____________

Learning Outcomes

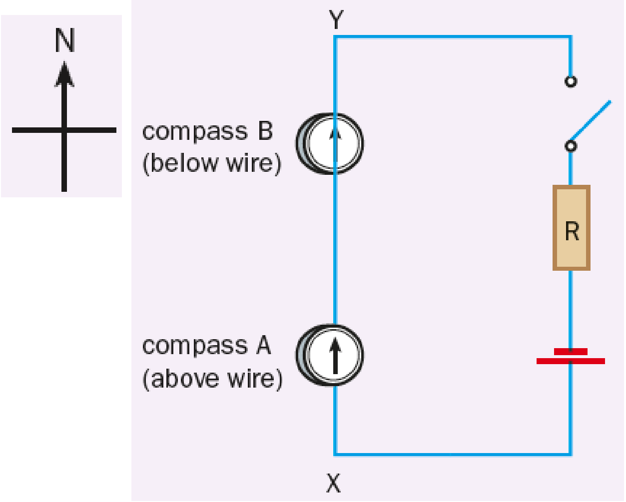
(a) draw the pattern of the magnetic field due to currents in straight wires and in solenoids and state the effect on the magnetic field of changing the magnitude and/or direction of the current
(b) describe the application of the magnetic effect of a current in a circuit breaker
(c) describe experiments to show the force on a current-carrying conductor, and on a beam of charged particles, in a magnetic field, including the effect of reversing
  (i) the current
  (ii) the direction of the field
(d) deduce the relative directions of force, field and current when any two of these quantities are at right angles to each other using Fleming's left-hand rule
(e) describe the field patterns between currents in parallel conductors and relate these to the forces which exist between the conductors (excluding the Earth's field)
(f) explain how a current-carrying coil in a magnetic field experiences a turning effect and that the effect is increased by increasing
  (i) the number of turns on the coil
  (ii) the current
(g) discuss how this turning effect is used in the action of an electric motor
(h) describe the action of a split-ring commutator in a two-pole, single-coil motor and the effect of winding the coil on to a soft-iron cylinder

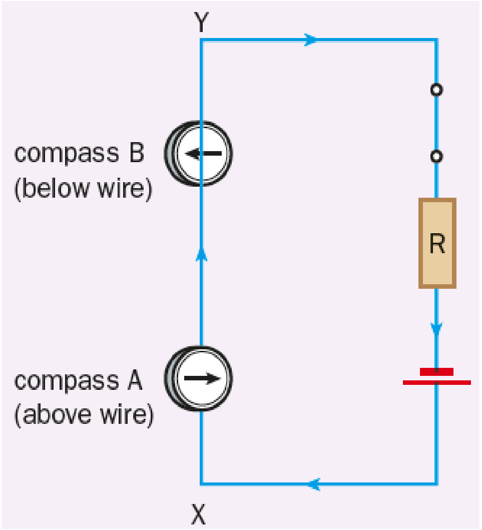
A. Prior Knowledge

Before T / F	**Statement**	**After T / F**
	1. All metals (Al, Cu, Fe) can be magnetized.	**F**
	2. Iron is attracted to magnet, so attraction is a sure test of magnetism.	**F**
	3. The strength of the electromagnet can be increased by changing the direction of the current.	**F**
	4. A force is acting on a current-carrying wire if it is in a magnetic field.	**T**
	5. A circuit breaker should be made by a permanent magnet.	**F**
	6. A circuit breaker and an electric bell make use of magnet in their operations.	**T**

A) Magnetic effect of current

When current flows through a wire, a **magnetic field** is produced around it.

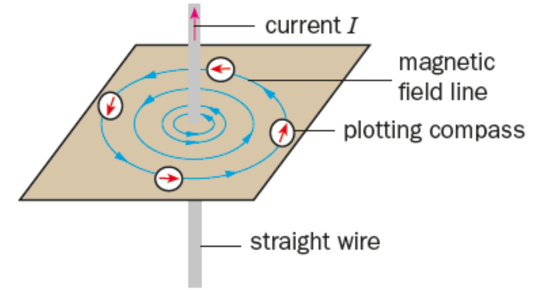


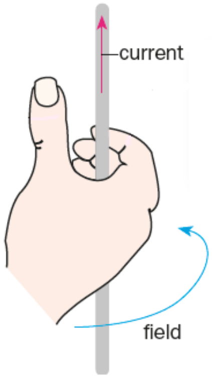


When no current flows through XY, the compass needles point to the **north**.

When current flows through XY, the needle of compass A points to the **east**. The needle of compass B points to the **west**.

B) Magnetic field of current-carrying conductors

	• The magnetic field of a straight, current-carrying wire consists of **concentric circles**. • The magnetic field is **stronger** closer to the wire.

<table>
<tr><th colspan="2">Method to identify direction of magnetic field in a wire: Right hand grip rule</th></tr>
<tr><td> </td><td>• The right-hand grip rule can be used to determine the direction of the magnetic field created by a straight wire carrying a current.
• The thumb points in the direction of the current.
• The other fingers point in the direction of the magnetic field around the wire.</td></tr>
</table>

The symbols below are used to represent the directions of **magnetic fields** or **currents**.

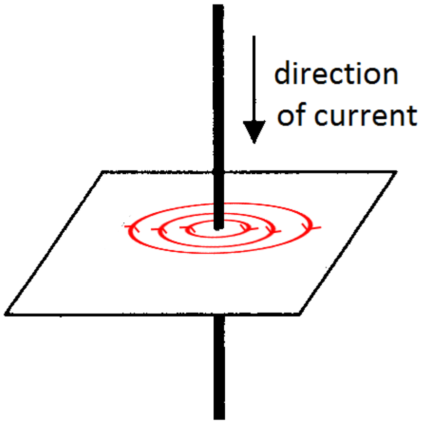
⊗	Represents the **current** flowing **into** the plane of the paper or the **magnetic field** pointing **into** the plane of the paper
⊙	Represents the **current** flowing **out of** the plane of the paper or the **magnetic field** pointing **out of** the plane of the paper

Practice

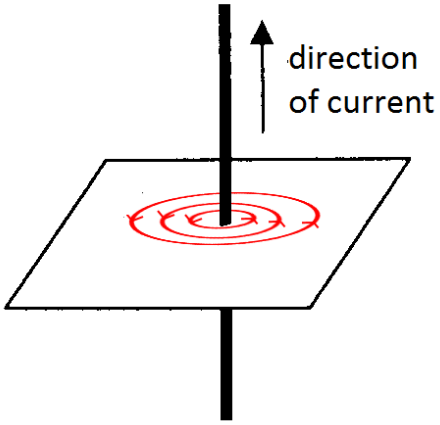
In the diagrams below, draw the magnetic field lines around the conductor.

On your diagrams, indicate clearly the direction of the magnetic field lines.

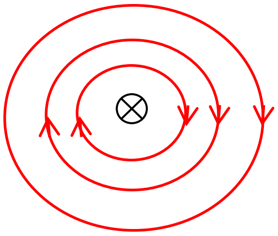
Side view



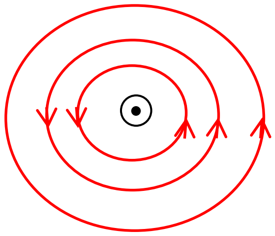
Side view



Top view



Top view

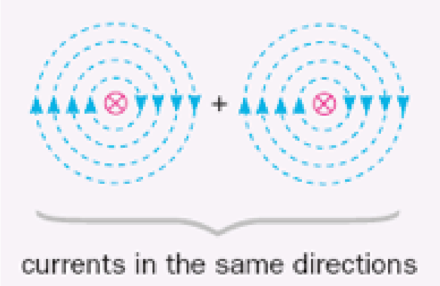


Points to note:

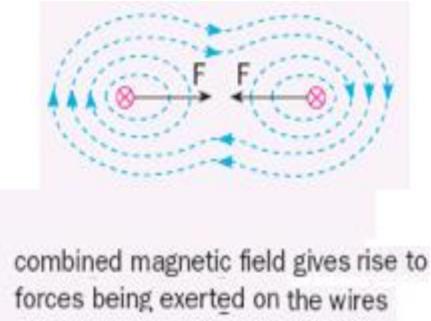
- The direction of the magnetic field of a current-carrying wire **reverses** when the direction of the current is reversed.
- The strength of the magnetic field of a current-carrying wire **increases** when the current is increased.

C) Interaction of magnetic fields between two current-carrying conductors

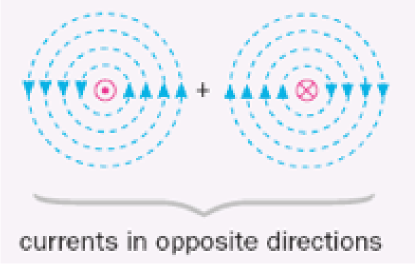
Top view



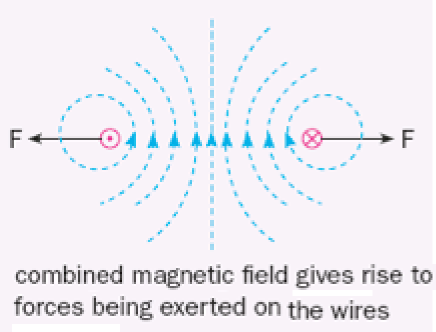
Top view



Top view



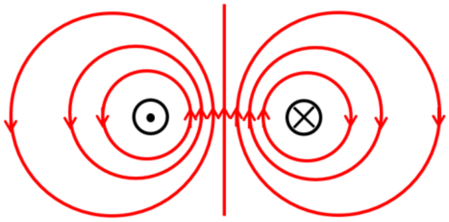
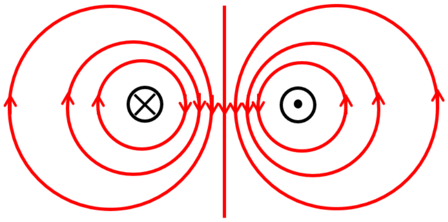
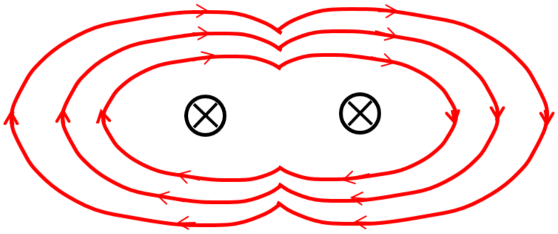
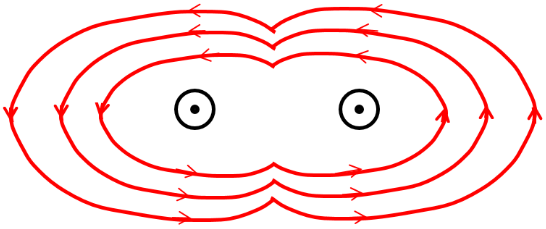
Top view



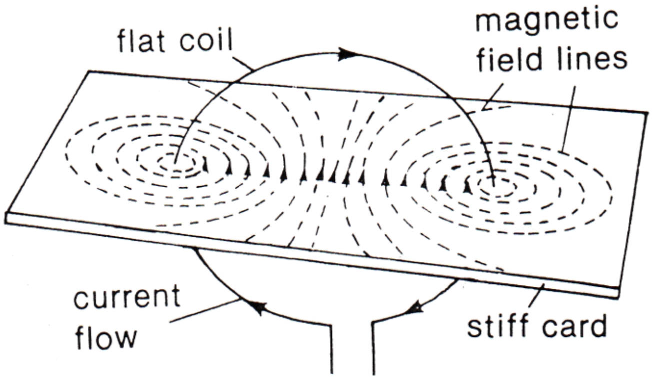
- Both current going in the **opposite** direction **(REPULSION)**
- Both current going in the **same** direction **(ATTRACTION)**

Practice

Sketch the magnetic field pattern around each of the current-carrying wires shown below and indicate the interaction between 2 current-carrying conductors.

D) Magnetic field of a flat coil



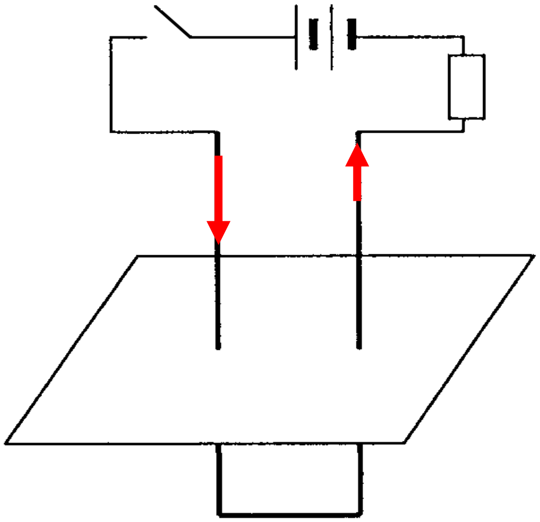
- The magnetic field strength of a flat coil can be increased by **increasing** the current flowing in the coil or **increasing** the number of turns of the coil
- The magnetic field is stronger in the region inside the coil because the fields from each part of the wire are in the **same direction** and the field lines are **confined to a small space**.

Practice

The diagram (right) shows a flat coil. The switch is closed and a current flows through the wire.

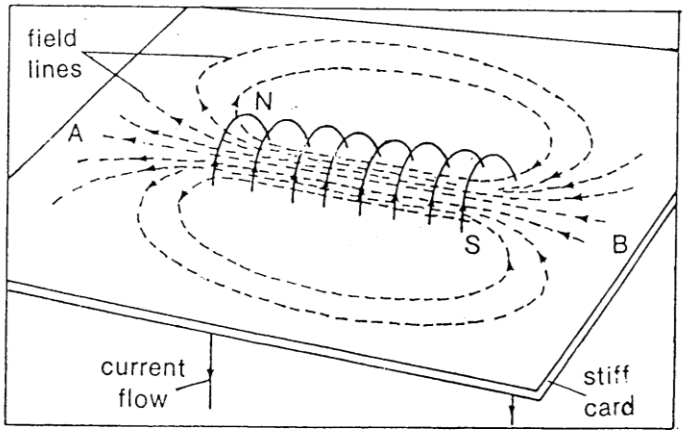
(a) Mark clearly on the wire the direction of current flow.

(b) Sketch the magnetic field caused by a current flowing in a flat coil.

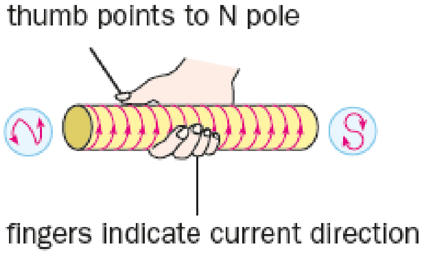


E) Magnetic field of a solenoid

Three methods to increase the magnetic field strength of a solenoid:

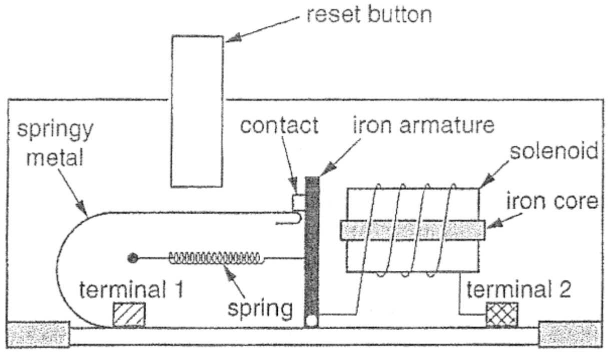


Method	Reason
Increase the **current** in the solenoid	Magnetic field strength is proportional to the amount of current flowing through the conductor.
Increase the **number of turns** of the coil	The magnetic effect is multiplied by the number of turns in a coil.
Place a **soft iron core** into the solenoid	A soft iron core focuses magnetic field lines within the coil.

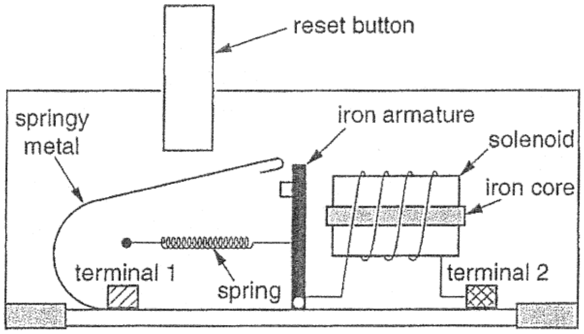
Method to identify poles in a solenoid: Right hand grip rule	
	• The direction of the magnetic field of a solenoid can be determined using the **right-hand grip rule**. • The fingers point to the direction of **current** in the solenoid. • The thumb points to the direction of **N-pole** of solenoid.

F) Application of Electromagnetism

The first diagram below shows a circuit breaker with the contact closed when the circuit is operating normally. The next diagram shows the same circuit breaker after a large current passes through the circuit.



Normal operating current



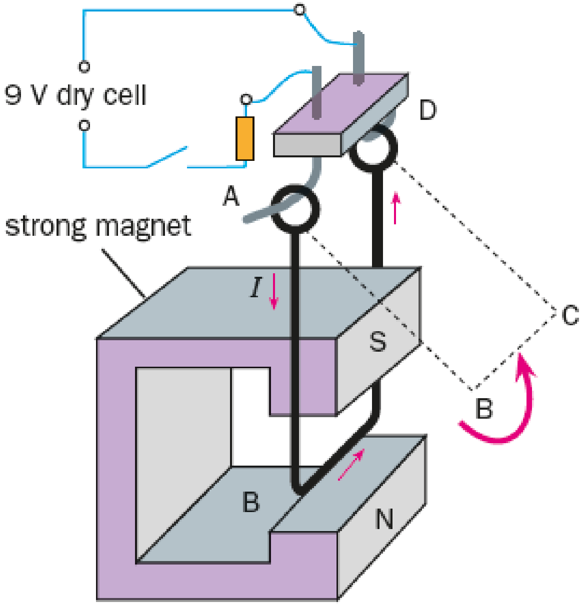
Large current

Describe in detail how the circuit breaker switches off the current when the current becomes too large.

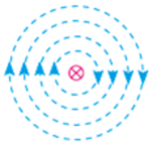
During normal operating, the current flowing through the solenoid causes a magnetic field in the iron core to form an electromagnet. However, the electromagnet is not strong enough to exert an attraction force to pull the iron armature.
When there is an increase in current flow, the magnetic field in the iron core increases, leading to a stronger electromagnet. The iron armature undergo magnetic induction and becomes attracted and move about the pivot.
The iron armature becomes out of contact with the springy metal, breaking the circuit and the current flow stops. When the current flow stops, the electromagnet loses its magnetism since iron is a soft magnetic material. The iron armature remains out of contact with the springy metal until the reset button is pushed.

G) Motor effect – Force due to magnetic fields

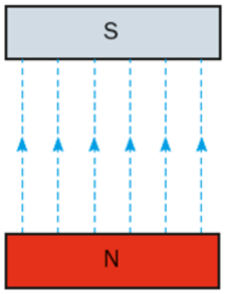
A current-carrying conductor experiences a **force** when it is placed in a **magnetic field**.



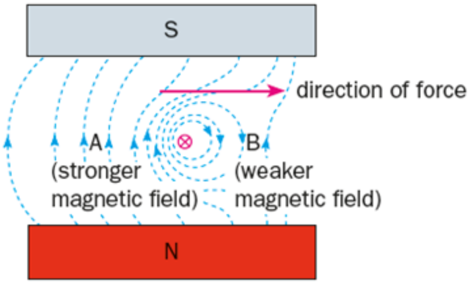
The force is a result of the interaction between the magnetic fields of the conductor and the magnetic field of the magnet.



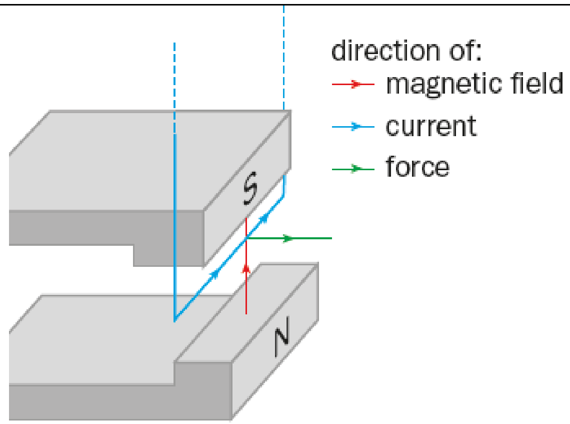
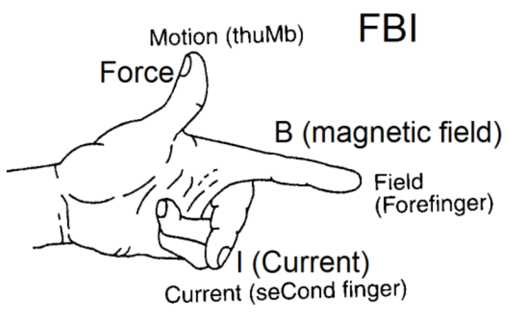
magnetic field due to current in wire



magnetic field between two magnetic poles

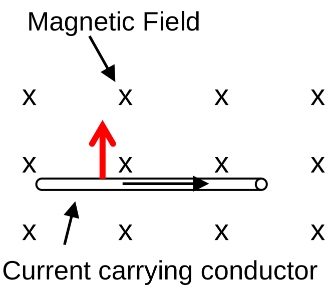


combined magnetic field of wire and magnetic poles

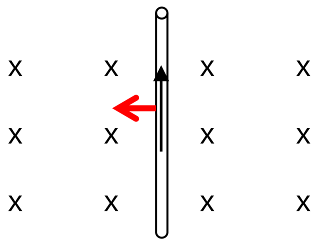
Method to determine the direction of force: Fleming's left hand rule	
	

Practice

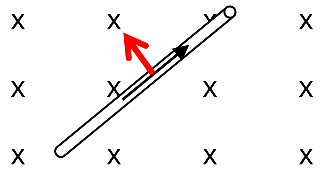
1. Using arrows, dots and crosses, indicate and state the direction of the force acting on the following current carrying wires.



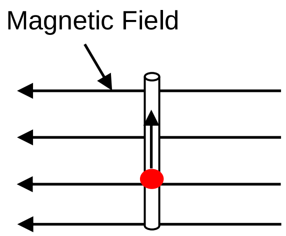
Direction of force:
Up



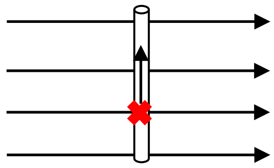
Direction of force:
Left



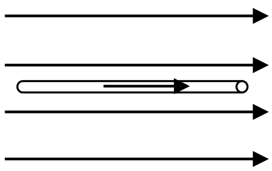
Direction of force:
Top left



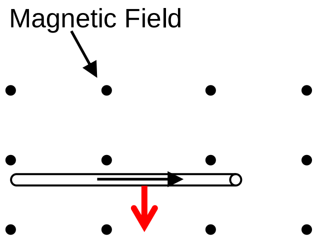
Direction of force:
Out of paper



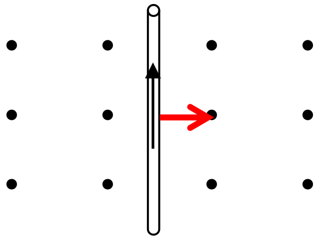
Direction of force:
Into paper



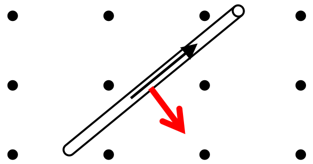
Direction of force:
No force



Direction of force:
Down

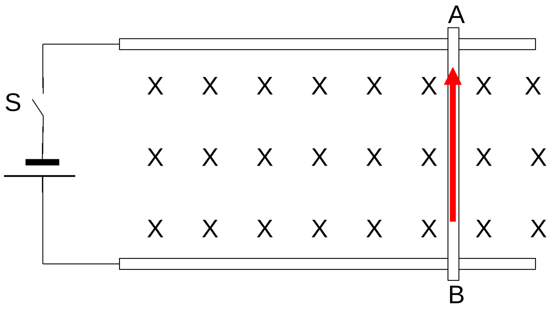


Direction of force:
Right



Direction of force:
Bottom right

2. A metal rod AB is placed on two smooth horizontal rails fixed on the bench as shown below. The set of crosses represent the magnetic field going into the page.



(a) On the diagram, draw the direction of the current in the rod when the switch is closed.
(b) Describe what will happen to rod AB when the switch is closed and explain your answer.

The rod AB will move towards the left. The movement is due to a force generated by the unbalanced magnetic field acting on both sides of the conductor. The direction of the force is given by Fleming's left hand rule.

(c) State the effect on the movement of the rod when the current is increased.

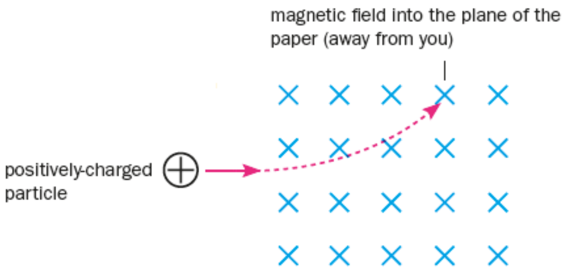
The rod accelerates more and moves at a greater speed towards the left.

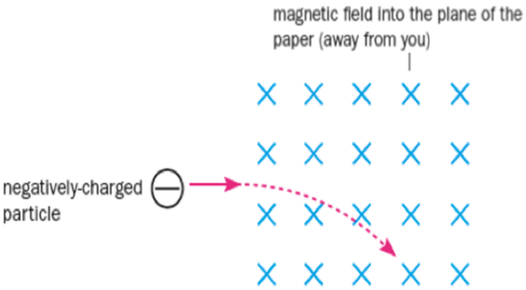
(d) State the effect on the movement of the rod when the current is reversed.

The rod would move to the right.

H) Deflection of charges in a magnetic field

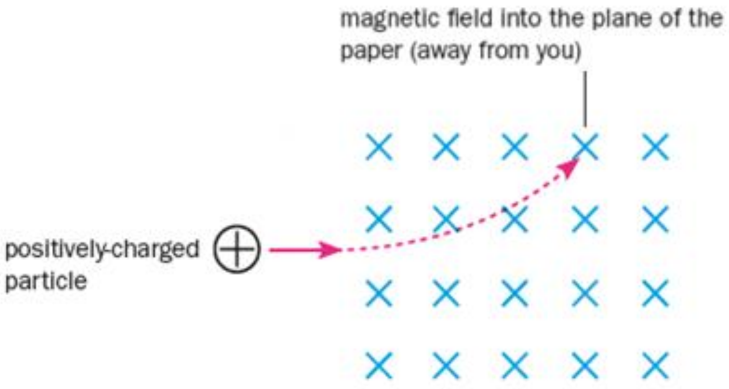
A charged particle moving through a magnetic field will experience a force. The direction of the force can be determined using **Fleming's left hand rule**.

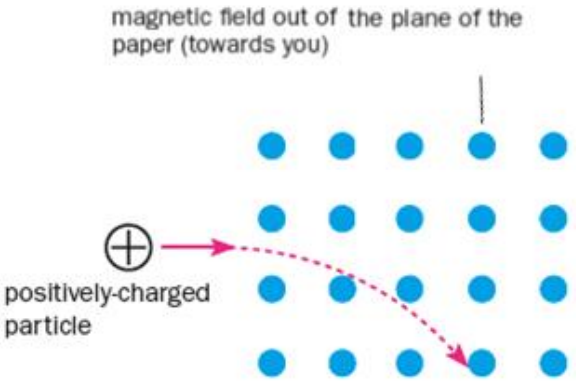




The direction of the force on a beam of charged particles is **reversed** when the charges of the particles are changed from positive to negative, and vice versa.

The direction of the force on a beam of charged particles is **reversed** when we reverse the direction of the magnetic field.

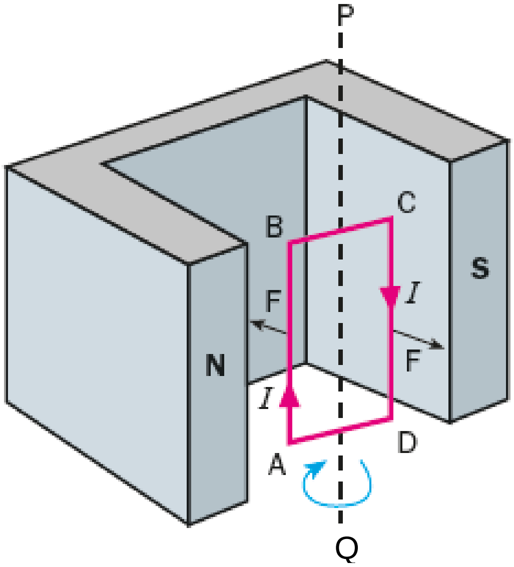


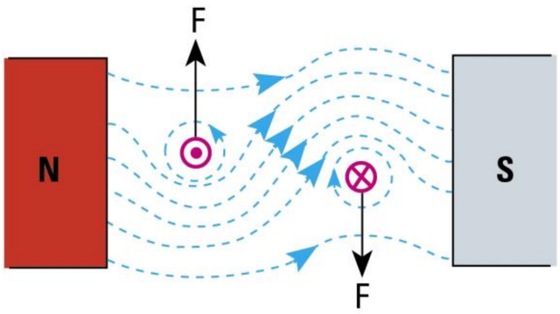


I) Turning effect on a current-carrying coil in a magnetic field

When the magnetic field of a permanent magnet interacts with the magnetic field of two current-carrying conductors (OR a rectangular coil), a **turning effect** is produced.

The direction of the turning effect is determined by applying Fleming's left-hand rule on the wire AB and wire CD separately.

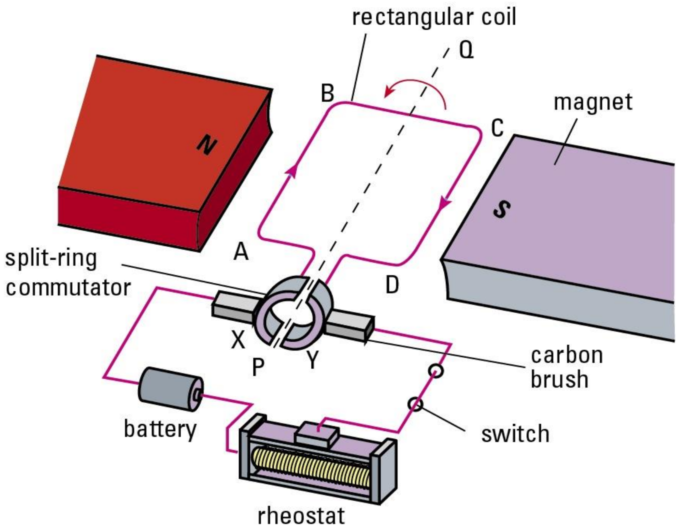




To increase the turning effect on the wire coil, we can

1. Increase the **number of turns** on the wire coil
2. Increase the **current** in the coil.

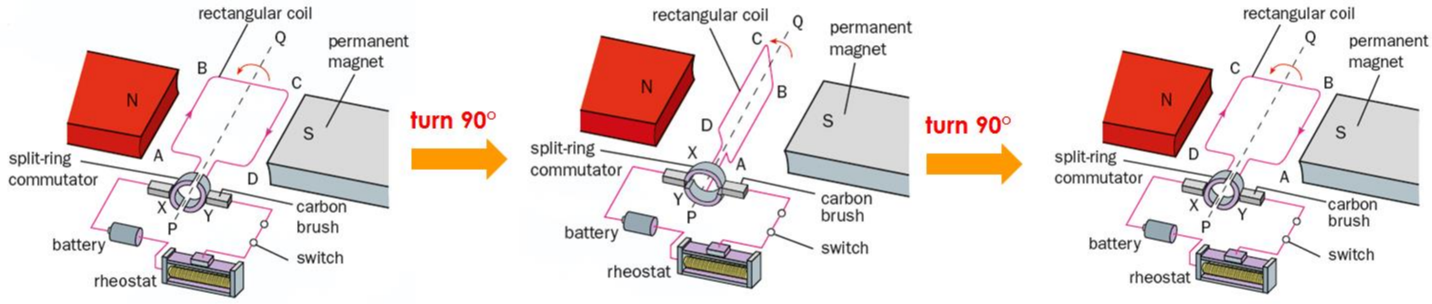
J) Application D.C. motor



The d.c. (direct current) motor is an electromagnetic device that converts **electrical energy** into **mechanical energy**. The motor consists of the following components:

- Rectangular coil connected in series to a battery and rheostat
- Permanent magnets
- Split-ring commutator
- Two carbon brushes

How the motor works



1. When the current flows through the loop ABCD, a **downward** force would act on the left-hand side AB, and an **upward** force on the right-hand side CD.
2. The loop would then rotate **anticlockwise** about axis PQ until it reaches the **vertical** position.
3. The current is now cut off[1] but **the momentum of the loop carries it past the vertical position**.
4. This reverses the current in the wire arm CD and now a **downward** force acts on it. An **upward** force now acts on the other wire arm AB.
5. Hence, the loop continues to move **anticlockwise**.

[1] The current is cut off because the Fleming's Left Hand rule cannot be applied in this position.

Use of the commutator (Split Ring)

To **reverse the direction of the current in the loop** whenever the commutator changes contact from one brush to the other. This ensures that the loop will always be **turning in one direction**.

Increasing the turning effect of the motor

1. Increase the **number of turns** of the wire loop
2. Increase the **current**
3. Place a **soft-iron core** within the magnetic field lines (concentrates magnetic field lines around the coil)

Practice

1. The magnetic field pattern produced by a coil carrying a direct current is similar to the magnetic field pattern of ____________________________ .
a. two straight parallel wires carrying direct current in the same direction
b. two straight parallel wires carrying direct current flowing in opposite directions
c. a permanent bar magnet
d. a horseshoe permanent magnet

2. A current-carrying coil in a magnetic field will experience __________________________ .
a. a force of attraction
b. a force of repulsion
c. forces of attraction and repulsion
d. a turning effect

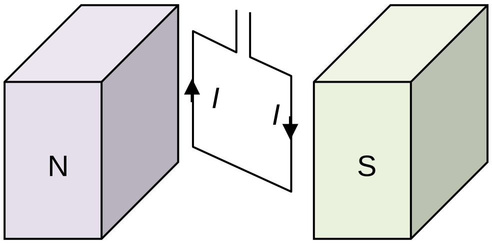
3. When a d.c. motor is connected to an a.c. supply, the coil will ____________________________ .
a. rotate faster
b. stop rotating
c. rotate at uniform speeds
d. rotate at different speeds

4. In a d.c. motor, no force is acting on the coil when it is perpendicular to the magnetic field. This is because ____________________________ .
a. no current is flowing through the coil
b. a small current is flowing through the coil
c. a large current is flowing through the coil
d. there is no magnetic field in the vertical position

5. Which one of the following appliances does not use the motor effect?
a. loudspeaker
b. microphone
c. galvanometer
d. ammeter

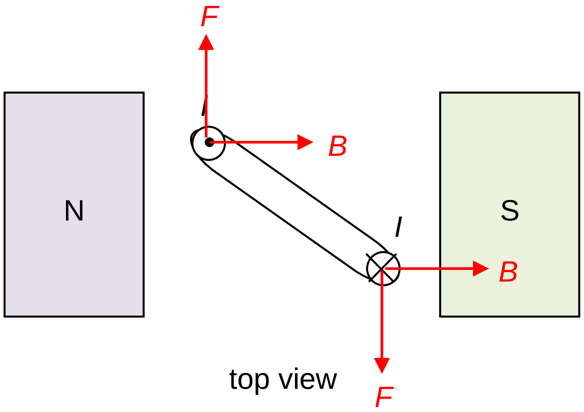
6. The function of the commutator in a d.c. motor is to _____________________________ .
a. decrease the resistance of the coil
b. reverse the direction of the current in the coil
c. increase the strength of the magnetic field
d. increase the magnitude of the current flowing into the motor

7. The set-up below shows a coil of wire placed between the poles of a magnet.



3D view

(a) The diagram below shows the top view of the set-up. Draw arrows to indicate the directions of the magnetic field and force acting on the coil of wire. Label the magnetic field *B* and the force *F*.



top view

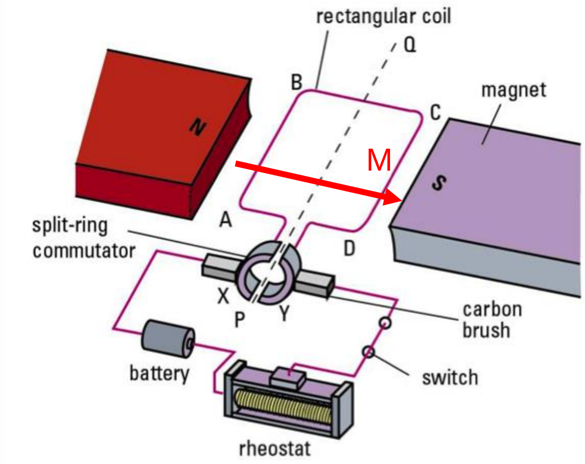
(b) Describe the subsequent motion of the coil in part **(a)**.

The coil rotates in the clockwise direction.

(c) How can you make the coil turn faster?

Increase the magnitude of the current. Increase the strength of the magnetic field. Increase the number of turns of the coil.

8. The diagram shows a simple motor.



(a) Indicate the direction of the magnetic field using an arrow. Label it *M*.

(b) Describe and explain what happens to the coil.

The coil rotates in the clockwise direction. Side AB of the coil experiences an upward force, while CD experiences a downward force. This can be shown using Fleming's left-hand rule. The two forces produce a turning effect on the coil.

(c) Explain the purpose of the commutator.

It reverses the direction of the current in the coil every half a revolution, ensuring that the coil continues to rotate in the same direction.

(d) State two ways to increase the turning effect of a motor.

Increase the magnetic field strength. / Increase the number of turns of the coil. / Insert a soft iron core into the coil. / Increase the magnitude of the current.