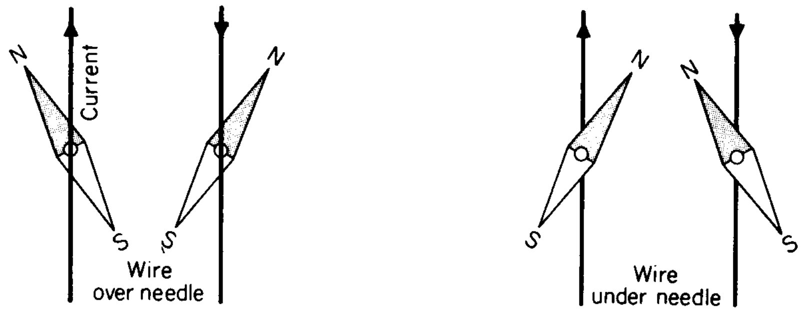
Hwa Chong Institution (High School) Name : ________________________ (   )
PHYSICS Notes Class : __________

Electromagnetism Date : __________

Electric Currents have Magnetic Effects

1. Introduction

It was discovered that a wire carrying a current was able to deflect a pivoted magnetic needle. The direction of the deflection depended on the direction of the current and also on whether the wire was above or below the needle, as shown in the figure.

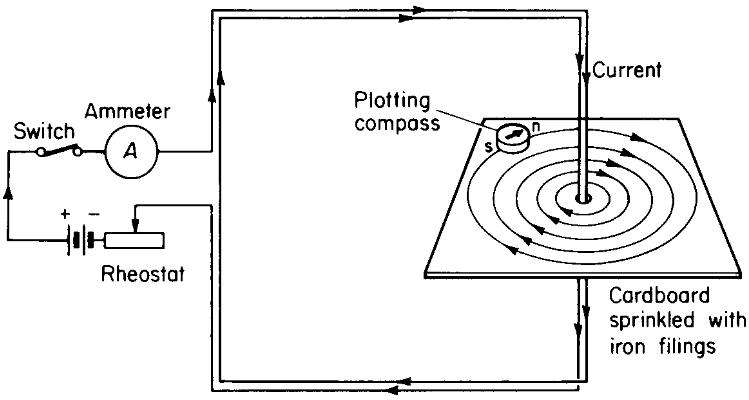


Oersted's experiment

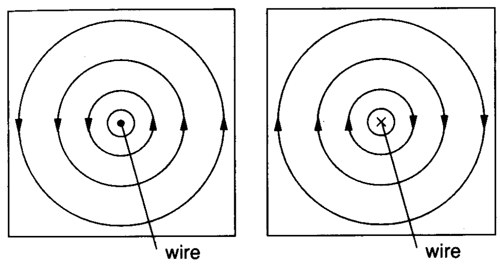
2. The followings describe the magnetic field patterns due to a current through different configurations of a wire.

A Straight Wire

Since an electric current has a magnetic effect, we should expect it to be surrounded by magnetic field. The way to do it is by placing a wire upward through a small hole in a horizontal cardboard as shown. A fine layer of iron filings is then sprinkled on the cardboard. The current is switched on and the card tapped gently. The filings set in a series of concentric circles about the wire as the centre.



Magnetic flux pattern due to current in a straight wire



(a) A dot in the wire shows the current coming out of the paper.

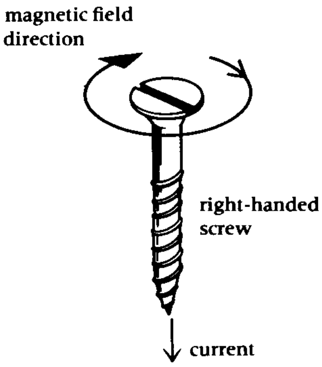
(b) A cross in the wire shows the current flowing into the paper.

A small plotting compass placed on the card indicates the direction of the field. If the current is reversed by changing over the battery connections, the compass needle will swing round and point in the opposite direction but the field pattern remains unchanged, as shown above.

Note:
- The magnetic field lines nearer the wire are closer to one another. This is because the strength of the magnetic field is stronger when it is nearer to the wire. The strength of the magnetic field decreases with distance from the wire. Therefore, the magnetic field lines are drawn further apart.
- The strength of the magnetic field also depends on the magnitude of the current through the wire. The larger the current, the greater would be the strength of the magnetic field.

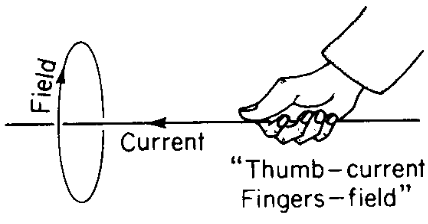
There are two ways to relate the direction of the magnetic field round a wire to the direction of the current flowing through it.

a) Maxwell's Corkscrew Rule



Maxwell's screw rule

b) Right-Hand Grip Rule



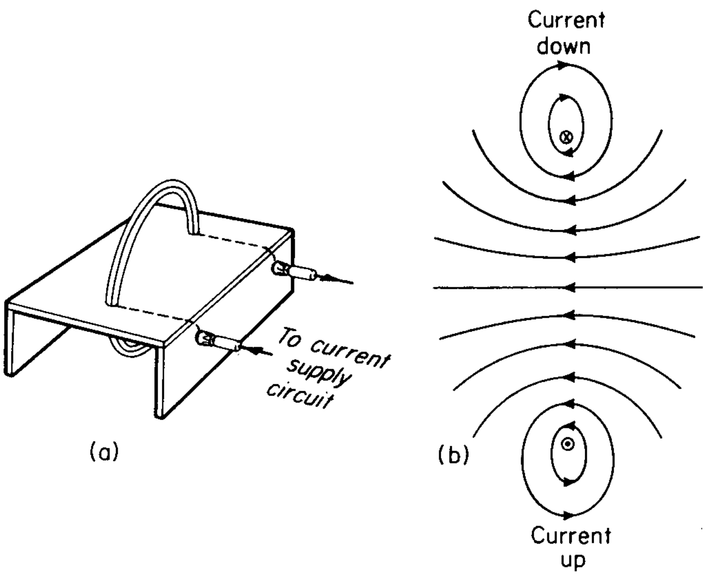
Right-hand grip rule

A Flat Coil

The magnetic field pattern due to a current flowing through a flat coil can be examined by the following set-up.

One feature of the magnetic field pattern of the flat coil is that the strength of the magnetic field is stronger along the inside of the coil than on the outside. Thus more magnetic field lines per unit area lie on the inside region of the coil. Also note that the field at the centre are straight and perpendicular to the plane of the coil.

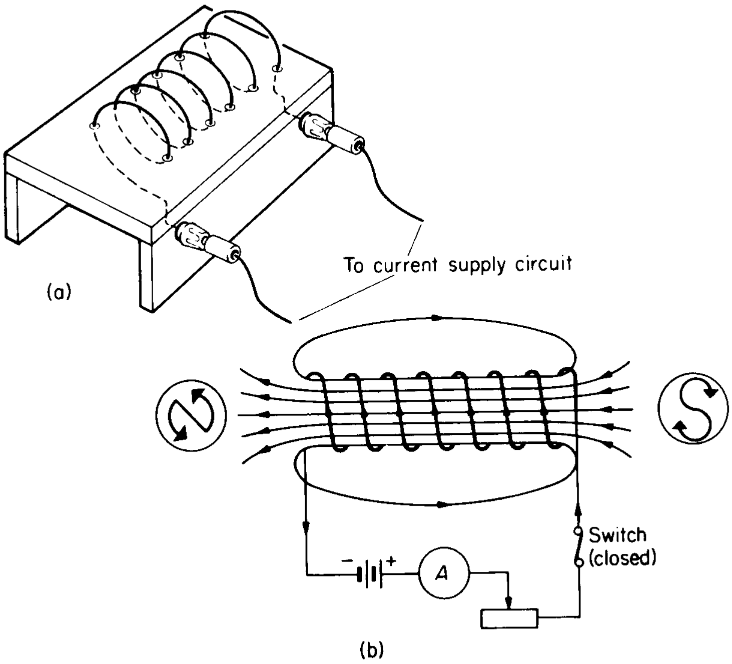
There are two ways to increase the strength of the magnetic field at the centre of the flat coil:
- increase the strength of the current;
- increase the number of turns of the flat coil.



Magnetic flux pattern due to current in a short coil

A Solenoid

The magnetic field pattern of a solenoid resembles that of the bar magnet. Hence, the solenoid can be said to have poles. The poles at each end of the solenoid must always be declared. How to tell what polarity is present? Use the Right-Hand Grip Rule, or look from one end and determine whether the current flowing through the coil is **aNticlockwise** (which will then be a North pole) or **clockwiSe** (which will then be a South pole).



Magnetic flux pattern due to current in a solenoid

The magnetic field is stronger inside the solenoid as shown above by the magnetic field lines which are closer together. The parallel field lines also show that the strength of the magnetic field is about uniform inside the solenoid.

The strength of the magnetic field can be increased by:
- increasing the strength of the current;
- increasing the number of turns per unit length of the solenoid;
- using a soft iron core within the solenoid.

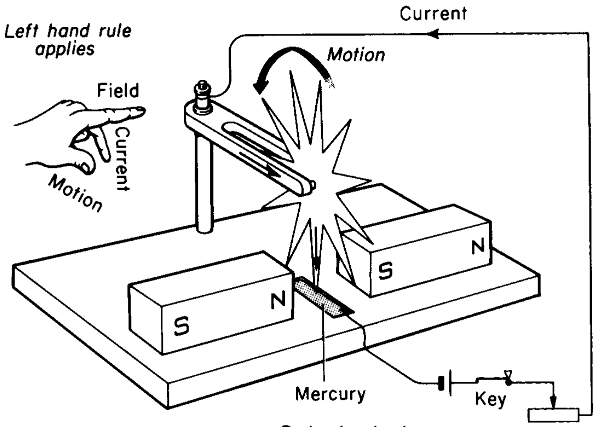
Electric Currents in Magnetic Fields

Force on a conductor in a magnetic field

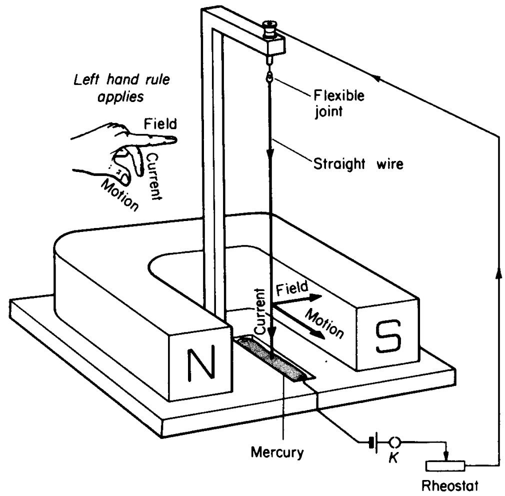
The two figures shown below illustrate how the direction of the force on a wire carrying a current is related to the direction of the magnetic field in which the wire is situated.

In the figure on the right, on closing the key **K**, the current flows downwards and the hanging wire swings forwards. This causes it to leave the mercury and break the circuit. The wire falls back, re-makes contact with the mercury and the action is repeated.

If the battery connections are reversed so that the current flows up the wire, the direction of the force on it will be reversed, and it will now swing backwards out of the mercury. The direction of the force on the wire may likewise be reversed by turning the magnet over so that the direction of the magnetic field is reversed.



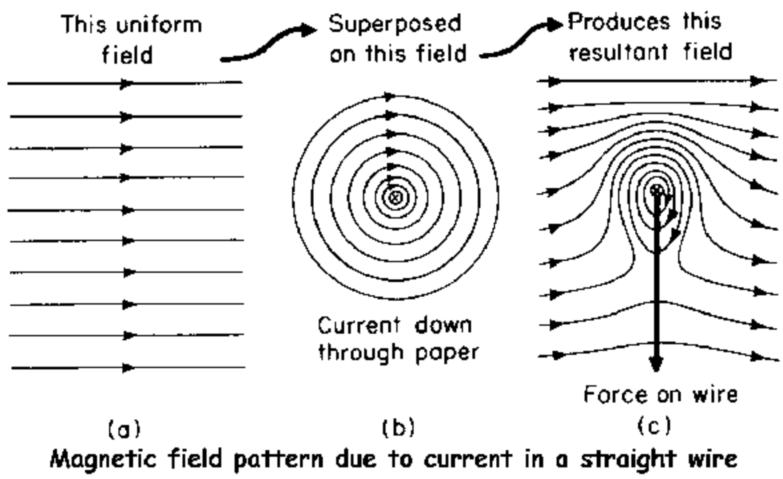
Barlow's wheel



Force on a conductor in a magnetic field (kicking wire experiment)

Fleming's Left-Hand Rule (motor rule)

Flemings LH Rule tells us the direction in which a current carrying wire moves in a magnetic field. The previous two figures illustrate the rule. To explain how the rule works, we have to make use of the properties of magnetic field lines as illustrated below.

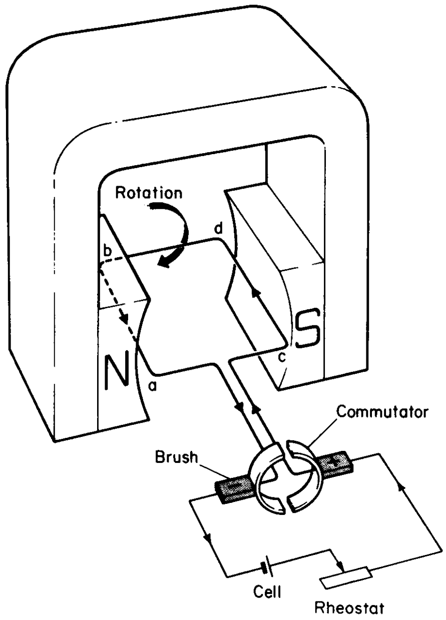


Magnetic field pattern due to current in a straight wire at right angles to a uniform magnetic field

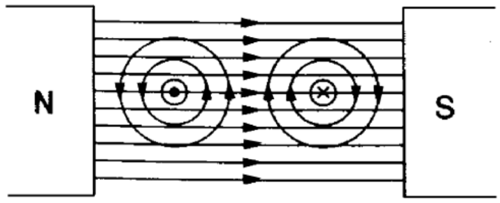
A resultant force is obtained when the parallel lines between the poles of the magnet are combined with the concentric lines due to the current in the wire. It will be noticed that the lines are closer together on one side of the wire than on the other, and thus they will exert a resultant sideways push on the wire. The action may be likened to that of an elastic catapult.

The simple electric motor

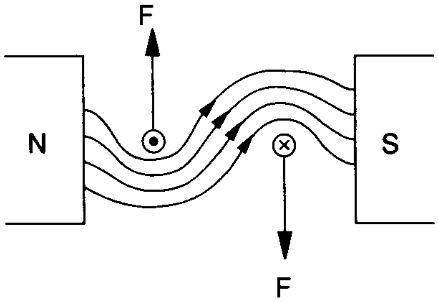
The figure below illustrates a simple direct current (d.c.) electric motor. It consists of a rectangular coil of wire mounted on a spindle so that it can rotate between the curved pole pieces of a U-shaped permanent magnet. The two ends of the coil are soldered respectively to the two halves of a copper split ring (or commutator). Two carbon brushes are caused to press lightly against the commutator by means of springs, and when these are connected in circuit with a battery and rheostat, the coil rotates. Carbon is chosen for the brushes because it is soft compared with the copper commutator. Worn carbon brushes are easy to replace, but a worn commutator would be expensive to replace.



Simple electric motor



(a) Individual fields



(b) Combined field

Suppose the coil is in the horizontal position when the current is first switched on. Current will flow through the coil in the direction shown, and by applying Fleming's LH rule, it will be seen that the side **ab** of the coil experiences an upward force and the side **cd** a downward force. These two forces form a couple which causes the coil to rotate in a clockwise direction until it reaches the vertical position. In this position, the brushes touch the space between the two halves of the commutator and the current is cut off. The coil does not come to rest, since its momentum carries it past the vertical, and when this has occurred, the two commutator halves automatically change contact from one brush to the other. This reverses the current through the coil, and consequently also reverses the directions of the forces on the sides of the coil. Side **ab** is now on the right-hand side with a downward force on it, and side **cd** on the left-hand side with an upward force. The coil thus continues to rotate in a clockwise direction for so long as the current is passing.

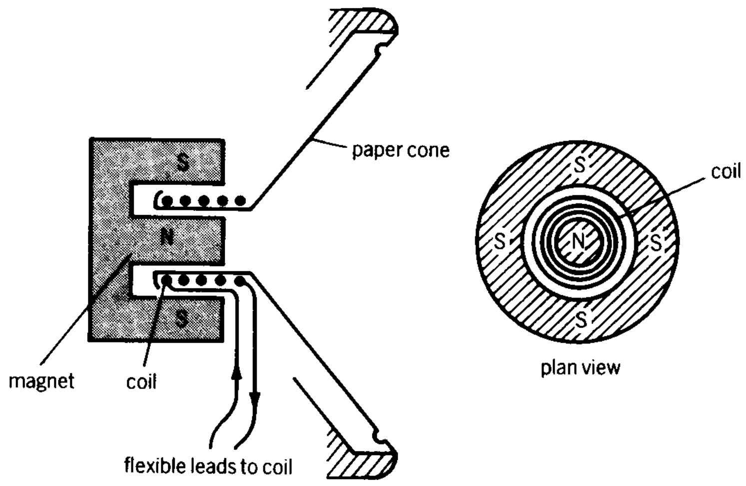
The magnetic field pattern in the simple electric motor is also shown in the diagram above.
In summary, a current-carrying rectangular coil in a magnetic field will experience a turning force.

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

- increase the number of turns of the wire loop;
- increase the strength of the current;
- place a soft iron core within the magnetic field lines.

Moving-coil loudspeaker

One useful application of the force on a current-carrying conductor in a magnetic field is the moving-coil loudspeaker. The permanent magnet used in a moving-coil loudspeaker has a central cylindrical pole (in this case, S-pole) and a surrounding ring pole (in this case, N-pole) to create a strong radial magnetic field in the gap between the poles.



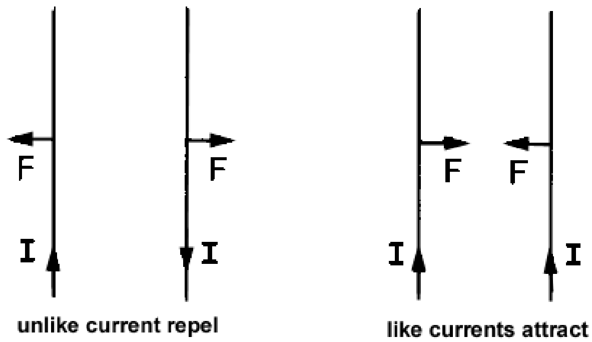
Moving-coil loudspeaker

When an alternating current (a.c.) passes through the coil, a force is produced which moves the coil forwards and backwards through a short distance. By attaching a paper cone to the coil, the air molecules in front of the coil and the paper cone are set into motion as the coil and the paper cone thrust forwards and backwards. The vibration of the cone as the current in the coil varies causes a sound of the same frequency to be transmitted through the air.

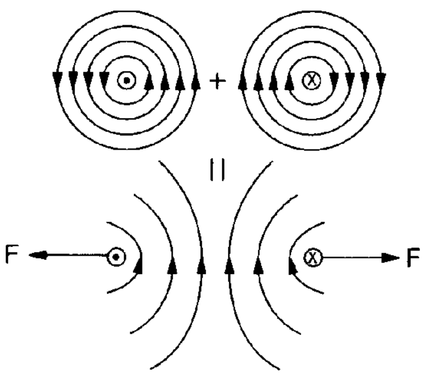
Other examples of instruments that make use of the moving-coil concept includes *the moving-coil galvanometer*.

Force between two Parallel Current-Carrying wires

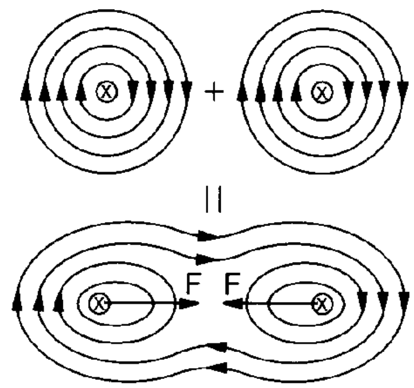
When two current-carrying wires are placed parallel to each other, we would expect the magnetic fields due to each wire to interact and a force will act on each of the wires. When the currents flow in opposite directions, the strips repel; and when the currents are in the same direction, they attract (as shown the figures below). In short, unlike currents repel, like currents attract.



To explain why there is a force acting on each of the parallel wires, we make use of the combined field due to the two wires, as shown below. The magnetic field pattern of a current-carrying wire can be found by applying the Right-Hand Grip Rule.



(a) Combining magnetic fields due to currents in opposite directions

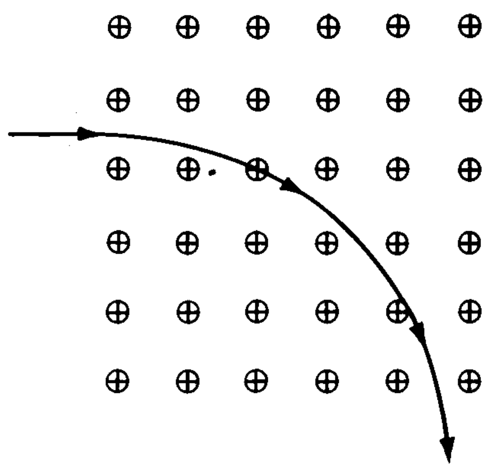


(b) Combining magnetic fields due to currents in the same direction

Force On a Charged Particle

So far, only the force on a wire carrying moving charge has been considered. However, any charged particle which is moving creates its own magnetic field and is affected when it moves through another magnetic field. There is a force on it just as there is on the charge in a wire, and Fleming's LH Rule again applies.

However, you must remember that this rule refers to conventional current direction and a beam of electrons moves in the opposite direction to the conventional current. The figure below shows a beam of electrons passing into a magnetic field which is directed into the paper. When inside the magnetic field, the force on the charged particle is always perpendicular to the direction of motion. Thus the direction of the beam is deflected. In fact, **the path taken by an electron in the magnetic field is an arc of a circle**.



Path of a charged particle in a magnetic field

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