BioMedical Admissions Test (BMAT)

Section 2: Physics

Topic P2 - Magnetism

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Properties of Magnets

Permanent magnets have **two** poles - one at each end - a north pole and a south pole.

Magnets exert forces on one another when they are placed within close vicinity:

- **Like** poles **repel** each other (e.g. North poles repels North poles)
- **Unlike** poles **attract** (e.g. North poles attract south poles)

The strength of attraction or repulsion is **stronger** the closer the magnets get together.

The poles of magnets can also **attract** magnetic materials such as iron, cobalt and nickel.

To test if an object is a permanent magnet, it must be able to **repel** another permanent magnet (attraction only proves that it is a magnetic material).

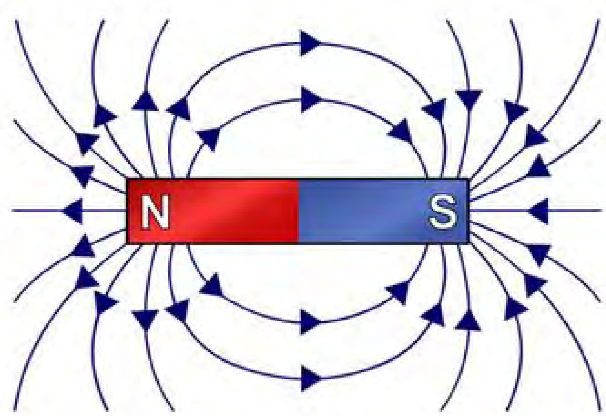
The north pole on a bar magnet is **'north seeking pole'** i.e. is attracted to the geographical north pole. Therefore, the geographical north pole must be a **'south seeking pole'**. The same principle holds true for the magnetic south pole.

Magnetic Fields

A **magnetic field** is an area around a magnet upon which magnetic forces act on other magnets or magnetic materials.

The magnetic field can be represented using **magnetic field lines** which:

- Start on north poles and end on south poles or form closed loops
- Cannot start or end in space
- Cannot cross one another
- Point in the direction of force that would be exerted on a free north pole (north to south)
- Are closer together where the field is stronger.



Magnetic field lines can be clearly depicted by sprinkling **iron filings** around a bar magnet where they form miniature bar magnets and align with the magnetic field.

The field lines can be traced using a **magnetic compass** as the needle will point in the direction of the field at each point that it is placed on.

Magnetic Materials

Magnetic materials are materials that become affected by magnetic forces when placed in a magnetic field.

Some magnetic materials gain and lose their magnetism more easily than others:

- **Soft** magnetic materials are easily magnetised but also lose their magnetisation easily e.g. iron.
- **Hard** magnetic materials are difficult to magnetise but once magnetised, they are difficult to demagnetise (increased time to demagnetise or require heating or striking the magnet to demagnetise) e.g. steel.

<u>Electromagnets</u>

Electromagnets usually consist of a **coil wrapped around a soft iron core**. Iron (softly magnetic) is used as it gains and loses its magnetism quickly, making it suited for electromagnets.

- ➔ When an electric current flows through the coils, the core magnetises creating a combined magnetic effect from the current and the strongly magnetised iron core.
- ➔ When the current is removed, the core quickly demagnetises causing the electromagnet to be turned off.
- ➔ Using a hard magnetic material would mean the electromagnet would take longer to turn on and off.

Inducing Magnetism

When you place a pole of a bar magnet near an unmagnetised magnetic material, there is a force of **attraction** experienced (never repulsion).

This means that the bar magnet has **induced** an opposite pole in the magnetic material i.e. holding a north pole near the magnetic material induces a south pole.

Induced magnetism is used to make permanent magnets by placing a hard magnetic field in a strong magnetic field such as a solenoid.

Electricity and Magnetism

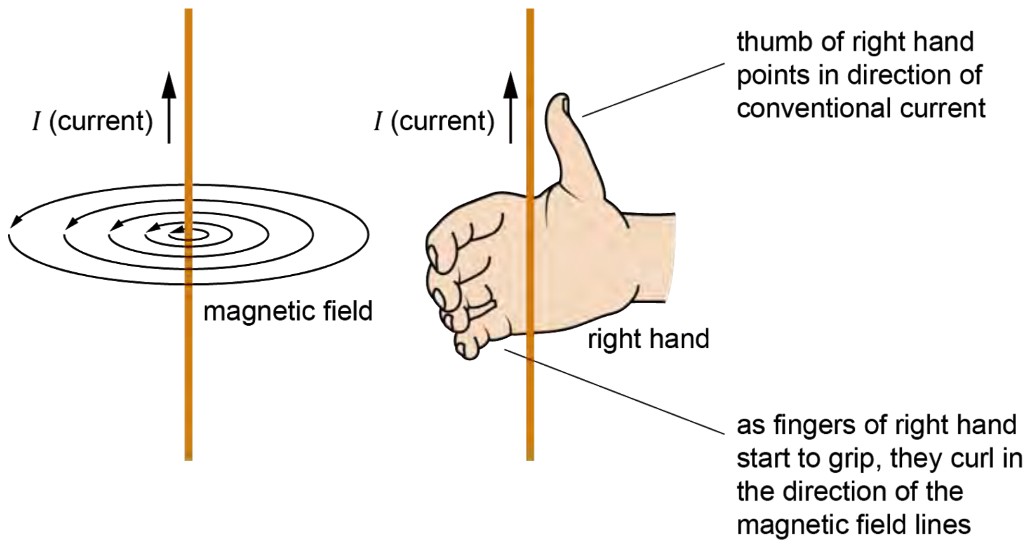
When **current** flows through a wire it creates a **magnetic field** in the surrounding area.

- ➔ Reversing the direction of the current reverses the magnetic field
- ➔ Increasing the current increases the magnetic field strength.

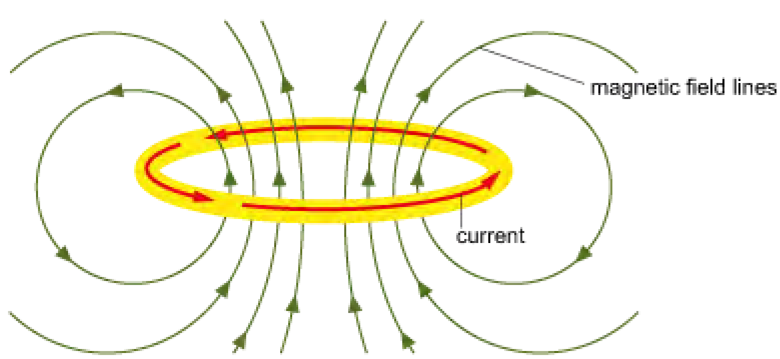
The magnetic field is a result of moving **charge carriers** and not the wire itself. A beam of charged particles such as electrons or ions moving through a vacuum will also create a magnetic field.

The magnetic field pattern around current a long straight current carrying wire:

- Consists of concentric circles.
- Circles get further apart (field strength decreases) further away from the wire.
- Have a direction predicted by the right hand grip rule.



When current carrying wire is wound into a **tight coil**, the magnetic field created by each part of the coil combines to form a strong field running through the cores centre. This produces the following pattern which can also be predicted by using the **right hand grip rule** at any point on the coil.



A long coil, also known as a **solenoid**, consists of lots of narrow coils wound together. The resultant field is very **uniform** through the centre of the solenoid:

- The field direction can be predicted by the right hand grip rule.
- The field is comparable to a bar magnet with poles at each end of the solenoid.
- Weak field at the sides of the solenoid and opposite in direction to the field inside the solenoid.
- Field strength and direction is controlled by current.

The poles can be identified by the direction the coils are wound. If you look at the end of the coils:

- If the coils turn **clockwise** - that is the north pole
- If the coils turn **anti-clockwise** - that is the south pole

Magnetic Field Strength

Magnetic field strength around a wire is dependent on:

1. The **current** - increasing current increases the magnetic field strength.
2. The **distance** from the wire - field strength decreases as you get further from the wire.
3. The **surroundings** of the wire - magnetic materials surrounding the wire can increase field strength.

Iron is a **ferromagnetic** material so each iron atom creates a magnetic dipole (north and south pole).

When these iron atoms are subjected to an **external magnetic field**, the **atomic dipoles** line up with this field which in turn creates a much stronger magnetic field.

➔ This is why iron cores are often used in electromagnetic devices (motors, generators etc.)

Electromagnets use **solenoids** to create a strong magnetic field whose strength is increased by:

- Increasing the number of turns per unit length.
- Using a soft iron core inside the coil.
- Increasing the current in the coil.

Permanent Magnets vs Electromagnets

There are key similarities between permanent magnets and electromagnets such as the **field shape** but there are key differences too:

1. Electromagnets can be turned on or off whereas permanent magnets are always on.
2. Electromagnets field strength can be **varied** whereas a permanent magnet's field strength is largely **constant**.
3. The polarity of an electromagnet can be reversed by reversing the current whereas a permanent magnet has a constant dipole.

Permanent magnets are made by placing a **hard** magnetic material (iron alloy, neodymium) in a strong external magnetic field.

- ➔ These magnets retain their strength for a long time but are weakened by **impact** and can be demagnetised by heating above their **Curie** temperature.

Electromagnets can have different field strengths by changing the **current** or the number of coils. However, current can only be increased so much before the wire becomes too hot. This problem can be eliminated by using **superconducting coils** (zero resistance) which require a very low temperature to function.

The Motor Effect

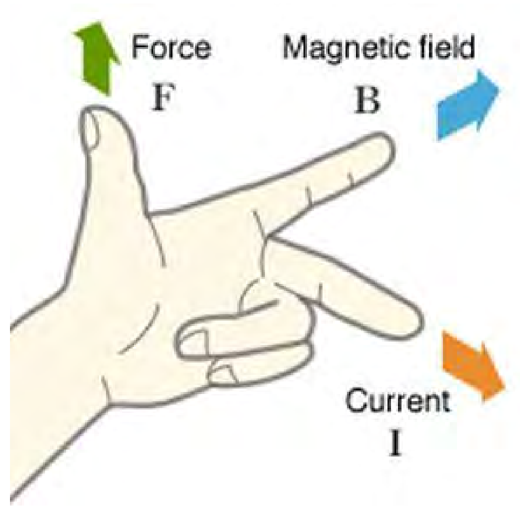
When a current carrying wire is placed in a magnetic field, it experiences a force. This principle is called the **motor effect**.

- ➔ This force is **perpendicular** to the direction of the current and the direction of the magnetic field.
- ➔ If the current carrying wire is **parallel** to the magnetic field, **no force** is experienced by the wire.
- ➔ If the current carrying wire is **perpendicular** to the magnetic field, then the force experienced is at a **maximum**.
- ➔ This force occurs as the magnetic field created by the current carrying wire interacts with the magnetic field of the permanent magnet creating a force on both the wire and the magnet.

Once again, it is the property of **moving charge** that creates a magnetic field so a beam of charged particles moving through a permanent magnetic field will also experience a force deflecting them.

The direction of the force experienced can be predicted using **Fleming's left hand rule**:

1. **Middle** = direction of the conventional **current** flow in the wire
2. **Index** Finger = direction of the **magnetic field** from the north pole to the south pole
3. **Thumb** = direction of the motor **force**



Reversal of the current **or** magnetic field will result in reversal of the motor force.

- ➔ However, reversing **both** of these parameters will not change the motor effect force.

If the current and the magnetic field are **not** perpendicular, you then use the **component** of the magnetic field that is perpendicular to the current.

The strength of the motor effect force is determined by:

1. **Current:** increasing the current increases the force.
2. **Magnetic field**: increasing the field strength increases the force.
3. **Length** of wire in the field: increasing the length of wire in the field increases the force.
4. **Angle** between current and magnetic field: greatest at 90 degrees and zero when parallel.

These factors can be combined to create the following equation to determine the magnitude of the motor effect force:

$$F = BIL$$

F is the motor effect force in Newtons (N)
B is the magnetic field strength in Tesla (T) - 1T = 1N/m/A
I is the current in Amperes (A)
L is the length of wire perpendicular to the field in Metres (M)

DC Motor

The motor effect is used on the DC motor where the motor effect is used to create a turning effect on a current carrying coil arising from a pair of motor effect forces acting in **opposite** directions on either side of a coil:

- A current carrying rectangular coil is placed in a **permanent** magnetic field.
- The motor effect forces on either side of the coil can produce a turning effect
- The maximum force occurs when the coil is in the plane of the field and the current is **perpendicular** to the field.
- The force is zero when the coil is perpendicular to the field and the current **parallel** to the field.

In order for the coil to rotate in the same direction, the current must be reversed every time the coil passes the vertical.

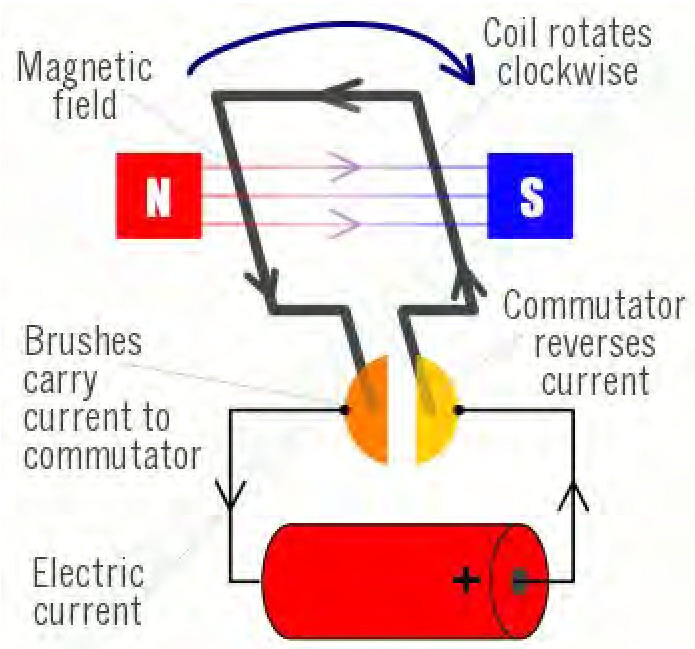
This is accomplished using a **split ring commutator** which rotates with the coil and connects to the DC power supply by two brushes and acts as a rotating switch.

The commutator is made from brass or copper and with graphite brushes which are low friction but make good electrical contact (brushes need replacing when worn down).

The turning effect of the coil is determined by:

1. **Current** in the coil: greater current creates a greater turning effect.
2. **Size** of the coil: the larger the area of the coil, the greater the turning effect.
3. **Number of turns** on the coil: the larger the number of turns, the greater the turning effect.

4. **Angle** of coil in field: maximum turning effect when the coil is in the plane of the field and zero when perpendicular to the field.
5. Winding the coil onto a **soft iron core**: this increases the magnetic field strength and increases the turning effect.
6. **Magnetic field strength**: a stronger magnetic field creates a greater turning effect.



Electromagnetic Induction

A voltage can be induced in a conductor by:

- Passing a conductor across the lines of a magnetic field **OR**
- The magnetic field line changes across the wire

It does not matter whether the coil or the magnetic field moves, if one crosses the other a voltage is induced in the wire or coil.

There is only an induced voltage when a change occurs (cutting across field lines or changing the field).

Electromagnetic induction always results in an induced voltage but will only produce a current if there is a **closed circuit.**

In order to generate a continuous voltage you need to continuously change the magnetic field. This can be done by:

- **Rotating** the magnetic field continuously
- Using an electromagnet connected to an **alternating current** (AC) supply

These are the principles used to create transformers and generators.

The magnitude of the induced voltage is directly proportional to:

- the rate at which a wire cuts magnetic field lines.
- the rate at which the magnetic field through a conductor (e.g. a coil) changes.

The stronger the magnet used equates to more field lines being cut per unit of time so using a stronger magnet **also** results in a greater voltage being induced.

If an electromagnet is used to generate a magnetic field, the induced voltage can be increased by:

- Increasing the **frequency** of the AC supply.
- Increasing the **amplitude** of the AC supply.
- Increasing the **number of coils** on the electromagnet.

An induced voltage always opposes the change that makes it in order to obey the principle of **energy conservation**. This means that the voltage induced will create a **dipole** in the coil that repels the magnetic field that created the voltage. You can use this rule to predict the current direction in your coil.

The induced voltage direction can be reversed by:

- Reversing the **direction** of cutting the magnetic field lines.
- **Decreasing** magnetic field strength instead of increasing it.

Alternating Current (AC) Generators

A simple AC generator consists of a coil rotating in a magnetic field causing the coil to **continuously** cut the magnetic field and induce a voltage.

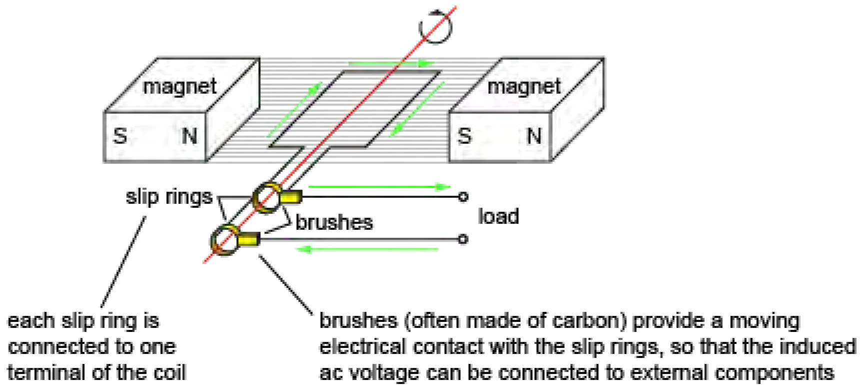
The voltage being induced **alternates** as the coil rotates and cuts the magnetic field in the opposite direction. Therefore this generator produces an AC output.

The **amplitude** of the output AC can be increased by:

- Rotating the coil more **rapidly** - this also determines the output **frequency.**
- Increasing the **magnetic field strength.**
- Increasing the **area** of the coil in the magnetic field.
- Increasing the **number of turns** of coil in the magnetic field.

All of these factors increase the number of **field lines** being cut per unit time.

The same effect can be accomplished either by moving a coil through a constant magnetic field or moving a magnetic field across a stationary coil.



Generators are an important use of electromagnetic induction as they are able to **transform** mechanical energy (in rotating the coil) to an electrical output. The source of mechanical energy can be from:

- **Chemical/nuclear energy**: Combustion of fossil fuels or nuclear fission heats water to produce high pressure steam which turns the generator.
- **Kinetic energy**: water flows through a water turbine or wind flows through a wind turbine to turn the generator.

Transformers are another important use of electromagnetic induction as they can convert AC at one voltage to AC of a different voltage. This is useful as different voltages of electricity have different uses.