SENIOR SIX TERM 2

TOPIC 2/5: MAGNETISM IN MATTER

Competency: The learner appreciates the magnetic properties of matter and uses them to model different useful magneto-electric devices.

Magnet

A **magnet** is a piece of metal which is able to attract another magnet or a magnetic material.

Lodestone is a naturally occurring magnet.

A magnet exerts magnetic forces on magnetic materials. The magnetic forces are:

(i) Forces of attraction.
(ii) Forces of repulsion.

Uses of magnets

- In construction of cycle dynamos, telephones, loud speaker, electric meters, current measuring instruments.
- To remove metal splinters from oil engine
- For door closures
- Electric bell
- Magnetic ink
- Computer memory cards.
- Electric motor
- Magnets are used in hospitals to remove iron pieces from the eye of patient.
- Making magnetic tapes used in audio and video recorders.

Properties of a magnets

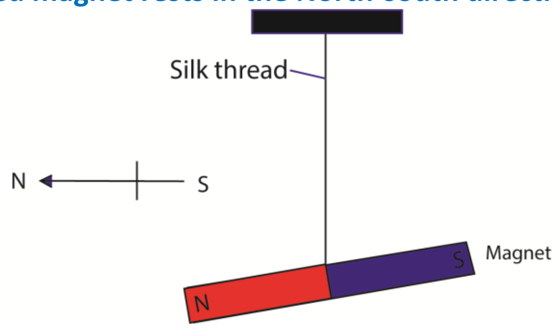
(i) It attracts other pieces of metals.

- Materials attracted by magnets are called magnetic materials
- Materials strongly attracted by magnets are called ferromagnetic materials such as iron, nickel steel, cobalt.

- Materials that are not attracted by magnets are non magnetic materials, e.g. copper, brass, aluminium, wood and plastics

(ii) **It possesses magnetic poles**- theNorth Pole and South Pole at the ends of a magnet. These are places where magnetic forces appear to be concentrated.

(iii) A freely suspended magnet rests in the North-south direction



Explanation; This is because the earth is a magnet having its south pole in the northern hemisphere and its north pole in the southern hemisphere so there is attraction between the poles of freely suspended magnet and the earth's magnet.

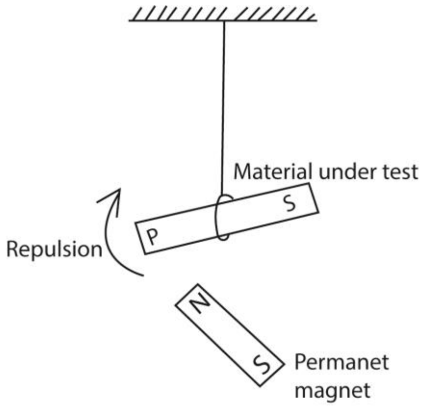
Law of magnetism

States that **like poles of magnets repel and unlike poles of magnet attract**

Testing for polarity of a pole

A known pole of magnet is brought near the ends of a material suspected to be a magnet. If repulsion occurs then that end of material is a like pole. The poles of a given magnet or magnetized material are tested by repulsion occurring between poles of a known magnet and that of the material whose polarity is to be tested.

NB: Repulsion is a sure test for polarity because repulsion only occurs due to like poles of magnets. While **attraction** is not a sure test because attraction can either result from unlike poles of magnets **or** from magnet and Ferromagnetic material which is not magnetized.



In this case P is a north pole

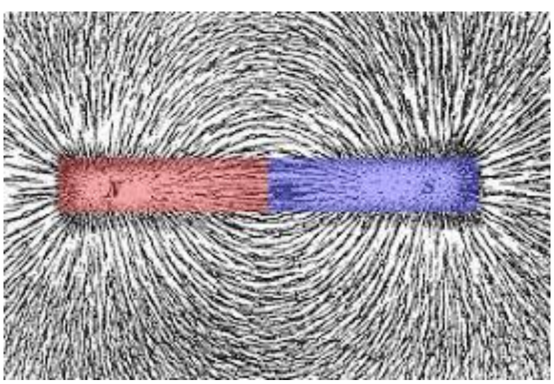
Magnetic field

This is a region of space around a magnet or a moving electric charge within which a force of magnetism acts.

In a magnetic field:

- A magnetic force can be experienced
- A moving charge experiences a magnetic force
- A current- currying conductor experiences a force
- An e.m.f is induced in a moving conductor.

The figure below shows Iron filings attracted to a bar magnet to show the magnetic field.



Magnetic Flux

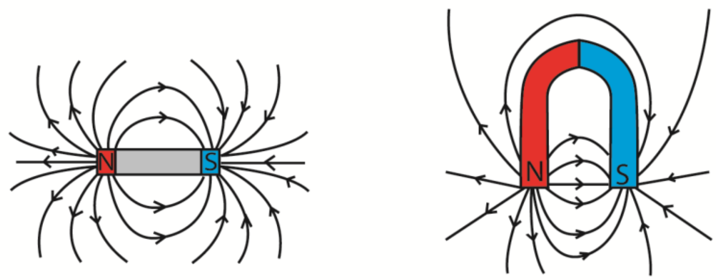
- All magnets, no matter what their shape, have two regions called magnetic poles; North and South.
- The north of a compass magnet is the end that points towards the Earth's north.

- Like poles repel, unlike poles attract
- Magnetic fields are lines of force draw from the North to the South of a magnet. The closer the Field lines the stronger the magnetic fields.
- The direction of magnetic field B, at any location is given by the direction of North Pole of the compass needle
- Magnetic field B is measured in N/Am or Tesla, T

Drawings of magnetic field patterns are shown below

(a) For a an isolated bar or horse Shoe magnet

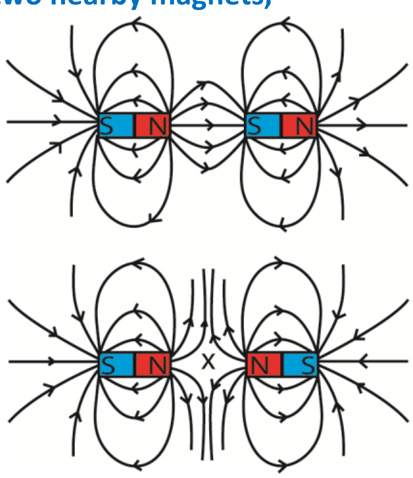
Magnetic field patterns around a bar and horse shoe magnets



Bar magnet   Horse shoe magnet

- Lines of force leave the North-Pole and enter the South Pole.
- An arrow should be drawn to show the direction of field lines
- Lines of force do not cross each other
- Magnetic field is strongest at the poles

(b) In two nearby magnets,

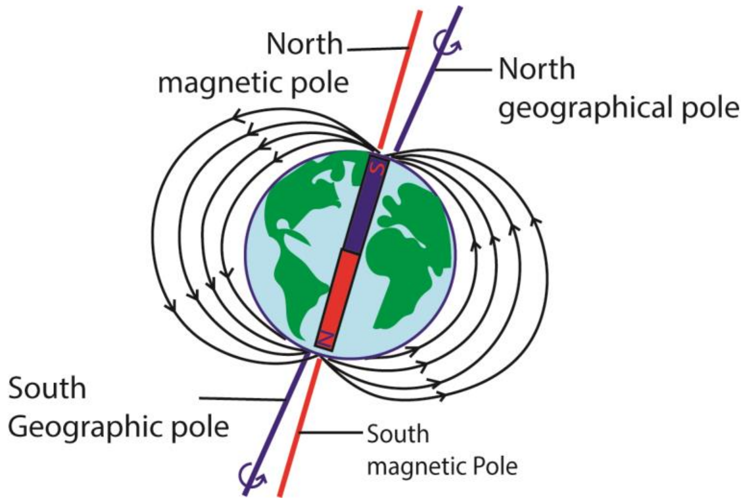


x- is a neutral point

Note that a line of the field will pass in opposite directions if like poles are nearby. A neutral point will be between them

(c) Earth's magnetic field

The earth's magnetic field lines are made up of parallel lines running from geographical south to geographical north.



The study of the earth's magnetic field involves:

(i) Two marginal lines called magnetic meridian and geographical meridian
(ii) Two angles called angles of dip and angle declination

Definitions

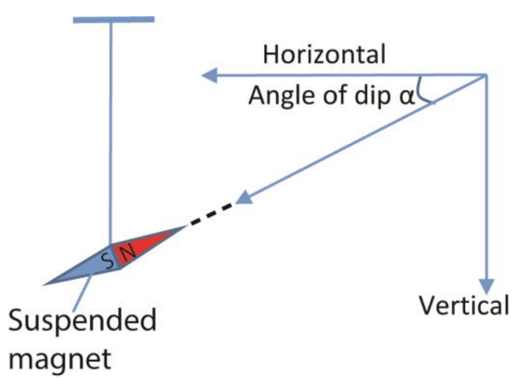
Magnetic meridian: This is the vertical plane containing the magnetic axis

Geographic meridian: this is the vertical plane passing through the axis of rotation of the earth.

Magnetic axis: This is the imaginary line passing through the earth's magnetic North and South Pole.

Geographical axis: This is the imaginary line through the center of the earth and passing through the geographic North and south.

Angle of dip (inclination) α: Angle of dip is the angle that the axis of a freely suspended bar magnet makes with the horizontal when the magnet settles



Generally the angle of dip varies from 0^0 at the equator to 90^0at the North Pole.

Magnetic Equator: This is the greatest circle in a horizontal plane perpendicular to the magnetic meridian where a freely suspended bar magnet experiences zero magnetic dip.

Explanation

At the magnetic equator, the earth's magnetic field lines are parallel to the horizontal. Therefore the angle of dip at the equator is zero, (α =0)

As one moves along a given longitude towards the North Pole, the resultant magnetic field lines meet the earth's surface at angles greater than 0^0 but less than 90^0 thus the angle of dip at such a position is also greater than zero but less than 90^0. i.e. $0^0 < \alpha < 90^0$.

At the North Pole, the magnetic field lines are normal to the earth's surface, thus they are perpendicular to the horizontal. Therefore the angle of dip at the North Pole = 90^0 or $\alpha = 90^0$.

Angle of declination (magnetic variance)

This is the angle between the earth's magnetic and geographical meridians. Or the angle between magnetic north and true north.

(d) Magnetic field patterns due to current carrying conductors

When a straight wire or conductor is carrying a steady or direct current, a magnetic fields is created or generated around it. For a straight conductor, the magnetic field pattern is uniform concentric circles around it.

The direction of magnetic field is determined by Right hand grip rule

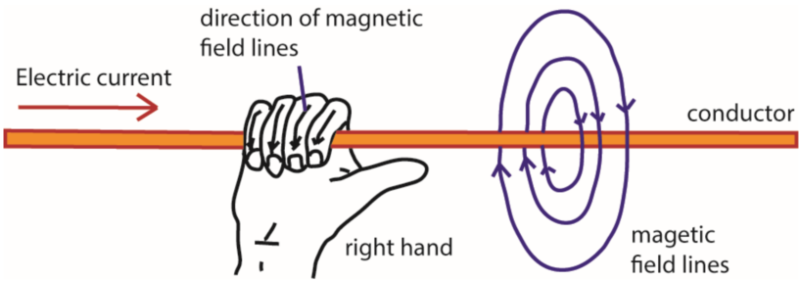
Right hand grip rule

Imagine gripping the conductor with the thumb straight in the direction of flow of current, with the finger curled around it, the direction in which the fingers gives the direction of magnetic field around the conductor.

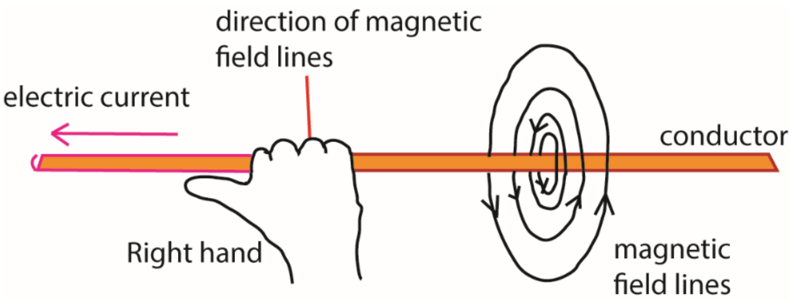
Magnetic pattern due to

(i) A straight (conductor carrying current I)

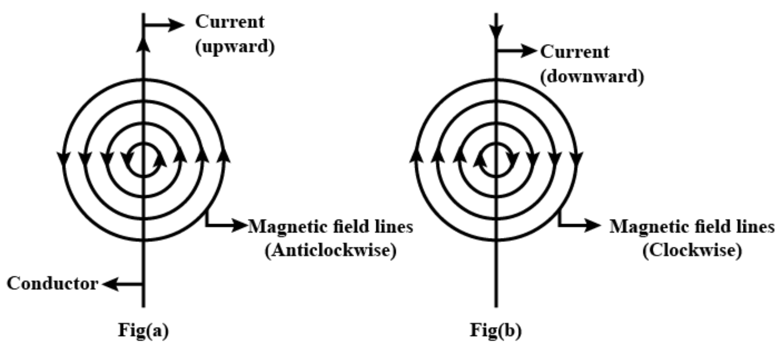
- **(Current from left to right)**



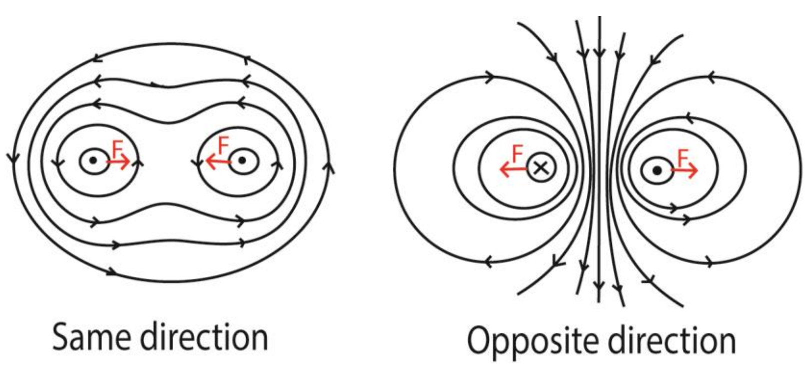
- **Current from right to left**



(ii) A straight wire carrying a current perpendicularly out of or into the plane of paper as shown in fig (a) and (b) respectively below

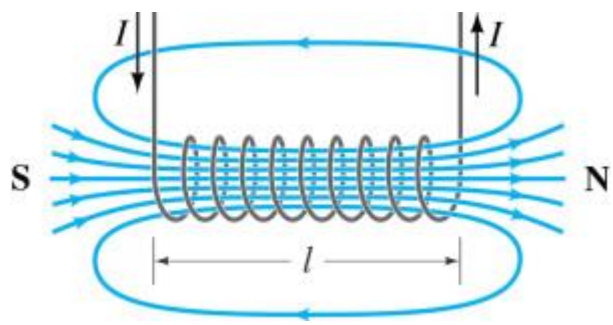


(iii) Magnetic field pattern due to two current carrying conductors having current flowing in same and opposite direction



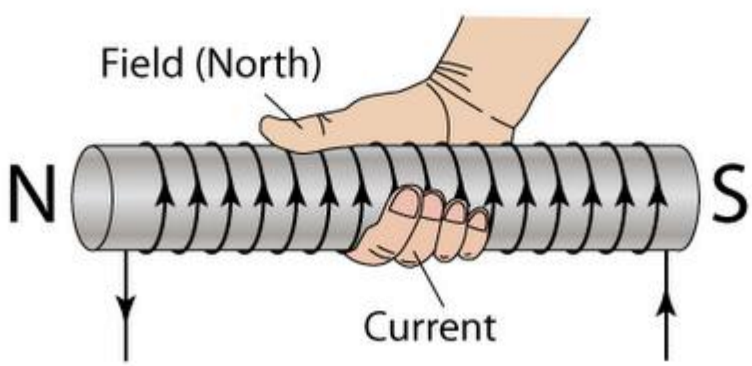
(e) Magnetic field pattern due solenoid carrying a current

Solenoid consists of a length of insulated wire coiled into a cylinder shape.



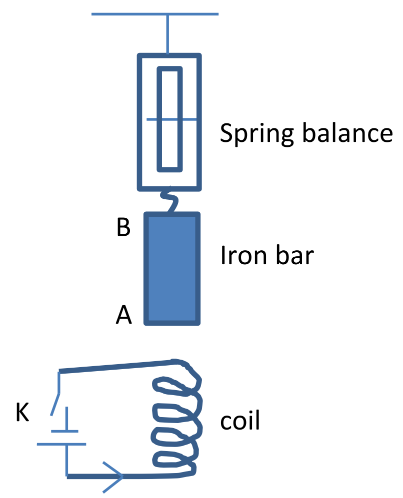
- Current in solenoid produces a stronger magnetic field inside the solenoid than outside. The field lines in this region are parallel and closely spaced showing the field is highly uniform in strength and direction.
- Field lines outside the solenoid are similar to that of a bar magnet and it behaves in a similar way – as if it had a north pole at one end and South Pole at the other end.
- Strength of the field diminishes with distance from the solenoid.
- Strength of the magnetic field can be increased by:
  - (i) increasing the current in the coil
  - (ii) increasing the number of coils in the solenoid; and
  - (iii) using a soft iron core within the solenoid.
- Reversing the direction of the current reverses the direction of the magnetic field.

- Right-hand rule can be used to find the direction of the magnetic field. In this case, point the wrapped fingers (along the coil) in the direction of the conventional current. Then, the thumb will point to the direction of magnetic field within the solenoid.



Example 1

The diagram shows a piece of soft iron bar suspended freely on a spring balance. One end of the bar is close to the end of the coil connected to a source of e.m.f via switch K.



When switch K is closed, the spring balance reads 50B. State the polarity of AB and explain your observation

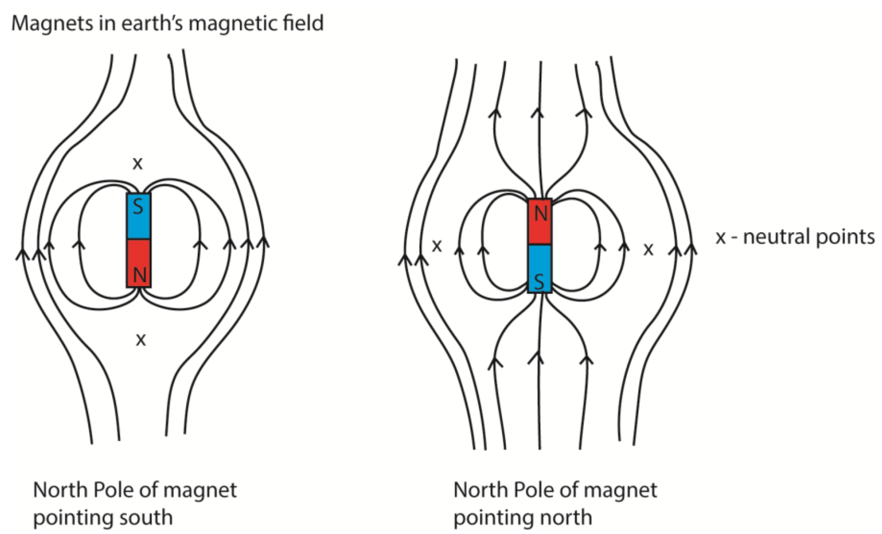
Solution

The upper end of the coil is a North Pole when K is closed.

Increase in spring balance reading shows that the iron bar is attracted. Thus A is a south pole while B is the North Pole because from right hand rule, the north pole of the coil is the top end.

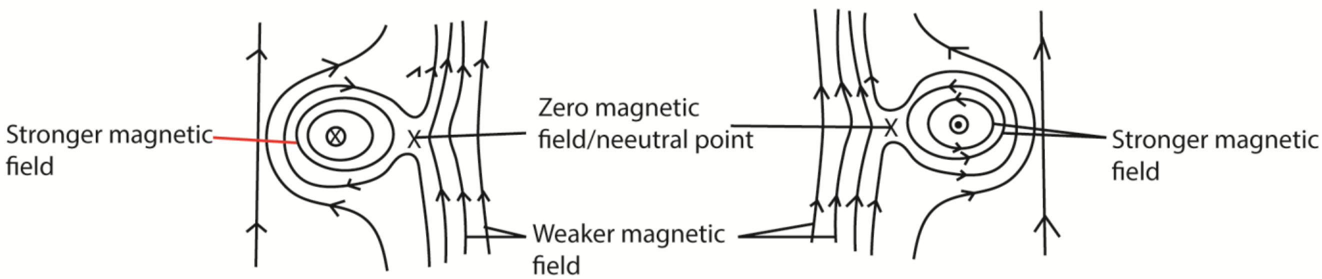
(f) Magnetic field due to a bar magnet placed in the earth's local magnetic field

(i) North Pole of the magnet facing down (geographical south)
(ii) North of the magnet facing Up (geographical North)



(g) A straight wire carrying a current perpendicular (across) the earth's local magnetic field

A straight wire carrying a current perpendicular (across) the earth's local magnetic field



(i) Current perpendicular into the plane of earth's local field.

(ii) Current perpendicular out the plane of earth's local field.

Neutral point

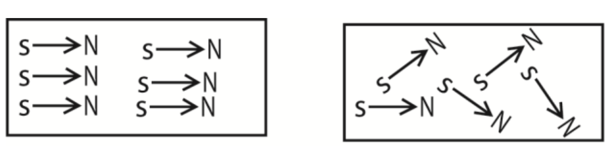
This is a region of space where two magnetic fields of equal magnitude and opposite direction cancel out. A magnetic dipole (compass needle) experiences zero magnetic force at this point.

Magnetic flux and magnetic flux density B, deduce its expression

Magnetic domain theory

A magnet is made us of tiny molecular magnets called dipole arranged in groups called magnetic domains, lined up with their N-poles pointing in the same direction.

In nonmagnetic materials, the domains are randomly mixed and their magnetic effect cancels each out.



Magnetized material

Unmagnetized material

Magnetization

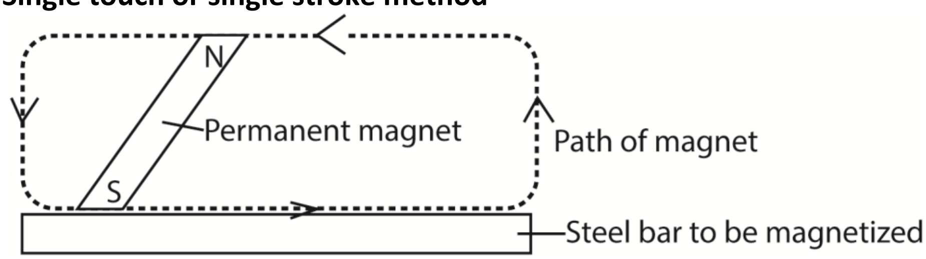
This is a process by which randomly arranged molecular magnet of a ferromagnetic material are arranged to point in one direction.

Methods of magnetization

These include:

- Single touch method.
- Double touch method.
- Electrical method using direct current (d.c.).

Single touch or single stroke method



Single stoking

A steel bar (Ferromagnetic material) is stroked several times from end to end using a bar magnet. The stroking is done in the same direction and using the same pole of bar magnet.

Molecular magnets explanation

The stroking of the magnet pulls the randomly molecular magnets to face in one direction thus material becomes magnetic.

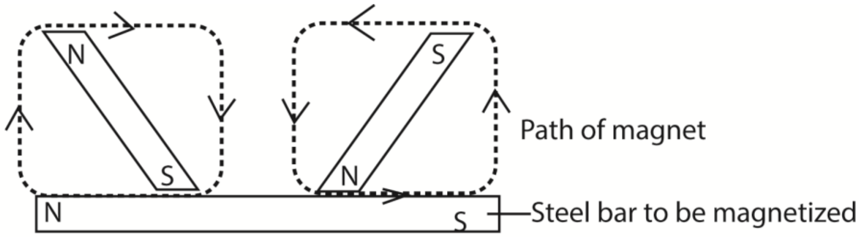
Disadvantage of single stroke method

The magnet produced has one pole nearer to the end as compared to the other pole

Identification of a pole

The pole of the bar magnet being used for stroking should be the same pole induced at the end of the steel bar from where stroking starts.

Double touch method or double stroke method

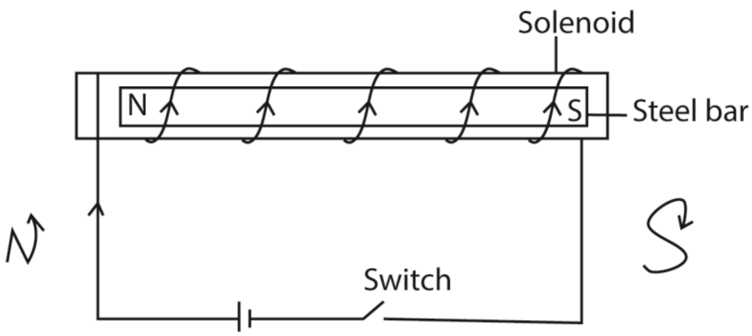


This uses two bar magnets placed at the centre of the steel bar with unlike poles as in the diagram. The stroking begins in the middle of the steel bar and ends at the opposite ends. The magnets are raised high at the end of each stroke before another one begins. This prevents reversing the acquired magnetism.

Molecular magnet
As stroking is done, the molecular magnets are pulled to face in one direction therefore creating poles at the ends of the steel bar.

Advantage of a double touch method over a single touch method
All poles are at both ends while for single touch method one pole is nearer to end than the other.
Disadvantages of double touch method over a single touch method
Double touch method is more expensive and tiresome.

Electrical method



The steel bar to be magnetized is placed inside a solenoid connected to the cells.
When direct current is switched on for some time, the bar will be magnetized

Note that with a.c. current the bar is not magnetized

Polarity of steel bar
The polarity of the steel bar depends on the direction in which the current is flowing. Current flows from positive to negative, so if on looking at the end of solenoid, current is flowing in a clock wise direction, that end will be South Pole but if it is flowing anti clockwise the end will be a north pole.

Induction method
When a magnetic material is kept close to a magnet for long time it gets magnetized.

Magnetic saturation
This is the maximum level of magnetization when the resultant magnetic axes of all domains in magnetic material are aligned with the magnetizing field.

Demagnetization

Demagnetization is the process through which magnets lose their magnetism
Demagnetization result in scattering molecular magnets to face in randomly.

Methods of demagnetization

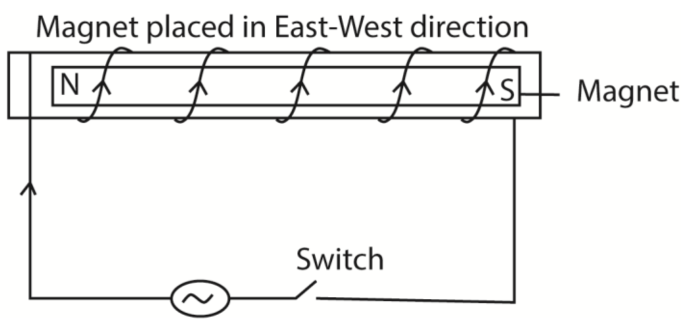
(i) By Heating:

Heating a magnetized material makes it loses its magnetism. This is because the temperature rise causes the vibrations of molecular magnets to become so great that their ordinary arrangement is destroyed.

(ii) By hammering:

Hammering a magnetized material placed in east-west direction, makes it loses most of its magnetism. This is because when a magnet is hammered, the vibrations of the molecular magnets increase which result in random arrangement.

(iii) By electrical method using alternating current

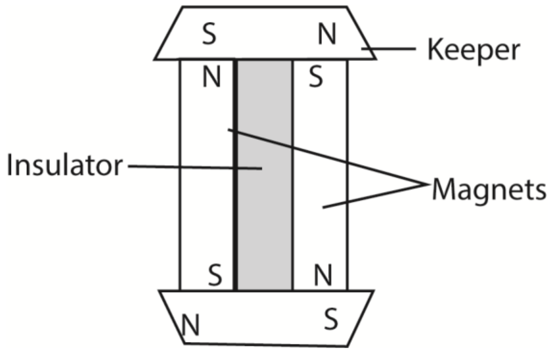


Here an alternating current is supplied to the solenoid in which the magnet is placed in east-west direction.

The alternating current (a.c.) causes the molecular magnet to change from orderly to random arrangement as current changes direction of flow every half cycle.
The demagnetized magnet should be removed from solenoid and stored along east- west direction to avoid magnetization due to earth's field.

Storing magnets

Small pieces of soft iron called keepers are placed across opposite **poles** of two bar magnets



These iron keepers become induced magnets and their poles neutralize the poles of the magnets. This ensures that there is no magnetic loss.

Soft and hard magnetic substances

Soft magnetic materials are substance that are easily magnetized and easily lose magnetism, e.g. soft iron.
Soft magnetic materials are used in making soft-iron core in transformers, dynamos, e.t.c.

Hard magnetic material are materials that are difficult to magnetize but retain their magnetism for long, e.g. steel.
Hardmagnetic materials are used in loud spears.

Paramagnetism

Paramagnetism is a form of magnetism where a material is weakly attracted to an external magnetic field because it has atoms with unpaired electrons. These unpaired electrons align with the applied field, creating an internal magnetic field in the same direction, but the material loses this magnetism once the external field is removed.

Characteristics of paramagnetism

- **Attraction to magnetic fields:** : Paramagnetic materials are weakly attracted to an external magnetic field.
- **Presence of unpaired electrons:**

The property originates from the presence of unpaired electrons in the atoms or molecules of the material. These electrons have a net magnetic dipole moment.

- **Temporary magnetism:** When the external magnetic field is removed, the material loses its magnetism because the electron spins return to a random orientation.
- **Weak effect:** Compared to ferromagnetic materials, the effect of paramagnetism is relatively weak.

- **Temperature dependence:** The strength of paramagnetism is dependent on the temperature of the material.

Examples of paramagnetic materials

Liquid oxygen (O_2), Aluminum, Magnesium, Lithium, Tantalum, and Molybdenum

Diamagnetism

Diamagnetism is a fundamental property where materials weakly repel magnetic fields by creating an opposing magnetic field, a result of electron orbital currents opposing external fields, making them move from stronger to weaker field areas. It's present in all substances, but usually overshadowed by stronger magnetic effects, though it's strong in superconductors (Meissner effect) and observable in elements like gold, copper, bismuth, water, and even humans in strong fields (magnetic levitation).

Key Characteristics:

- **Repulsion:** Diamagnetic materials are repelled by magnets, unlike ferromagnetic or paramagnetic materials which are attracted.
- **Induced Magnetism:** An external field induces a temporary magnetic moment in the opposite direction, according to Lenz's Law.
- **Weak Effect:** Generally very weak and requires sensitive instruments, except in superconductors.
- **Universal Property:** All materials exhibit diamagnetism; it's just often masked.
- **Negative Susceptibility:** They have a negative magnetic susceptibility ($\chi < 0$).

Examples:
Water, copper, gold, silver, bismuth, mercury, wood, plastics, and even air.

Thank you
Dr. Bbosa Science