MAGNETISM

Magnetism is phenomenon by which certain materials attract or repel one another due to the presence of a magnetic field. It is mainly produced by moving electric charges or the alignment of magnetic domains within materials such as iron, cobalt, and nickel. Materials that exhibit magnetism are called magnets,

A magnet is a piece of material that attracts other materials.

It produces an invisible force around it called magnetic force, which pulls (attracts) objects to it or pushes away (repels) objects from it.

Magnets are grouped into two categories namely;

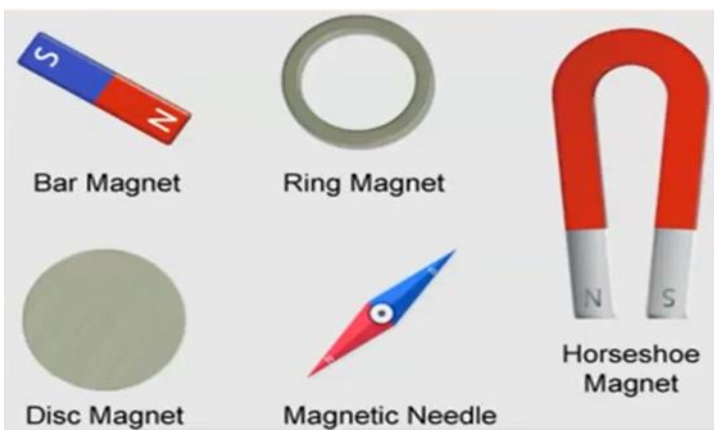
1.Natural Magnets:

These are magnets that are found in existence and are not made by people. They exist naturally on Earth. One common example of a natural magnet is Lodestone

2.ARTIFICIAL MAGNETS:

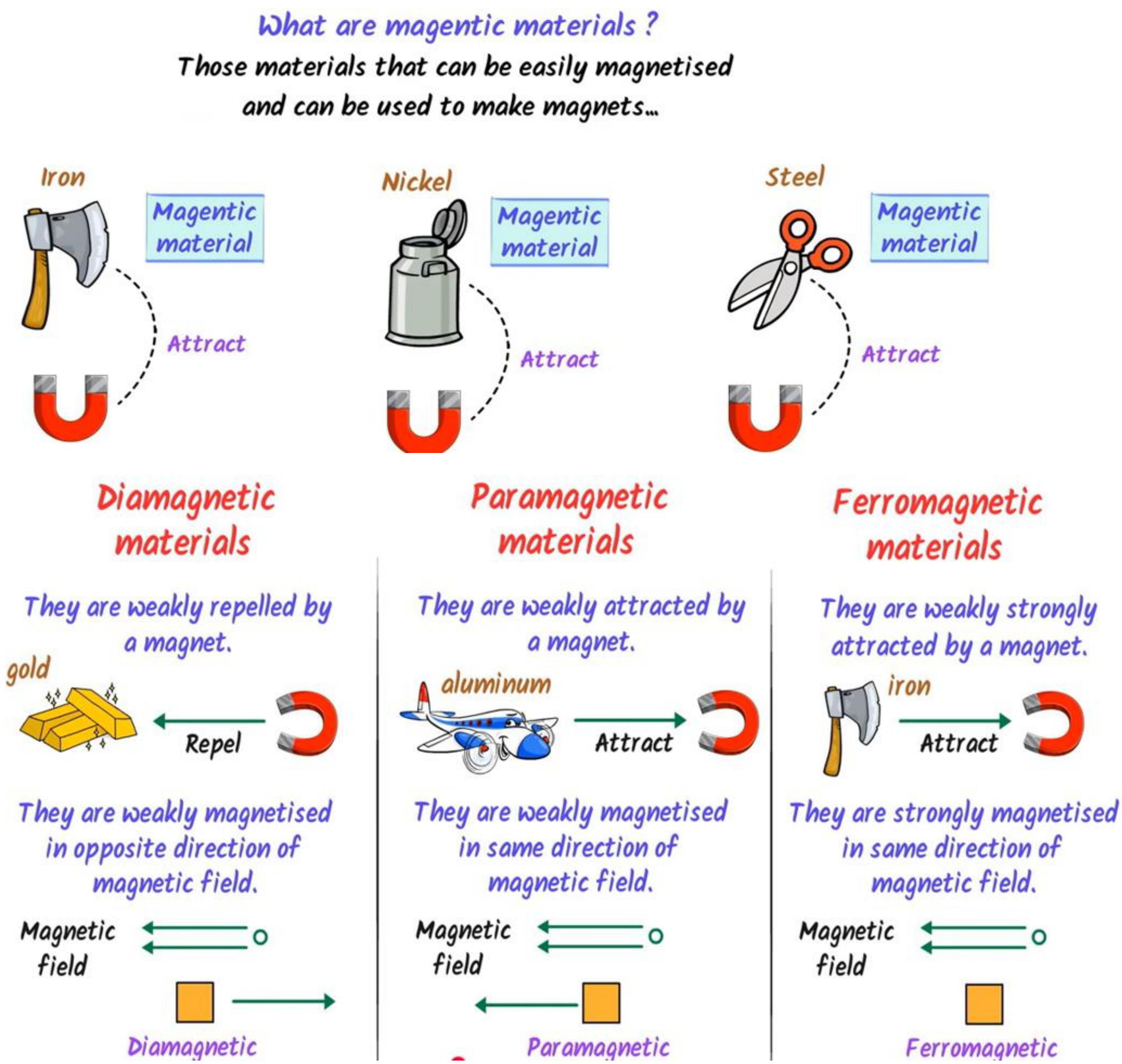
These are man-made magnets made from materials like iron and steel. They can be made into different shapes.

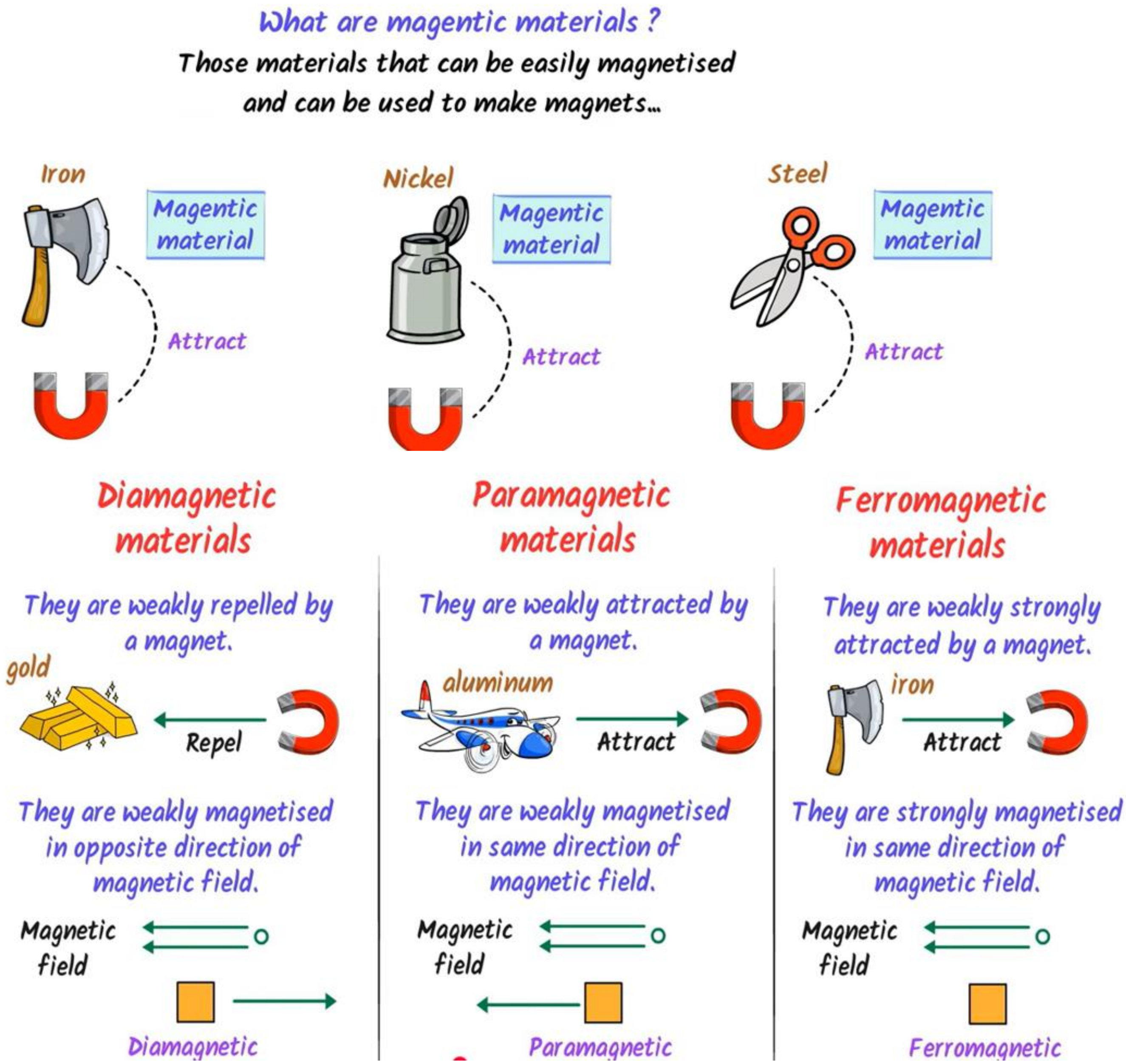
Examples include:



MAGNETIC MATERIALS:

Magnetic materials are materials that can be attracted or repelled by a magnet.


What are magentic materials ?
Those materials that can be easily magnetised
and can be used to make magnets...
Iron
Magentic material
Attract
Nickel
Magentic material
Attract
Steel
Magentic material
Attract
Diamagnetic materials
They are weakly repelled by a magnet.
gold
Repel
They are weakly magnetised in opposite direction of magnetic field.
Magnetic field
Diamagnetic
Paramagnetic materials
They are weakly attracted by a magnet.
aluminum
Attract
They are weakly magnetised in same direction of magnetic field.
Magnetic field
Paramagnetic
Ferromagnetic materials
They are weakly strongly attracted by a magnet.
iron
Attract
They are strongly magnetised in same direction of magnetic field.
Magnetic field
Ferromagnetic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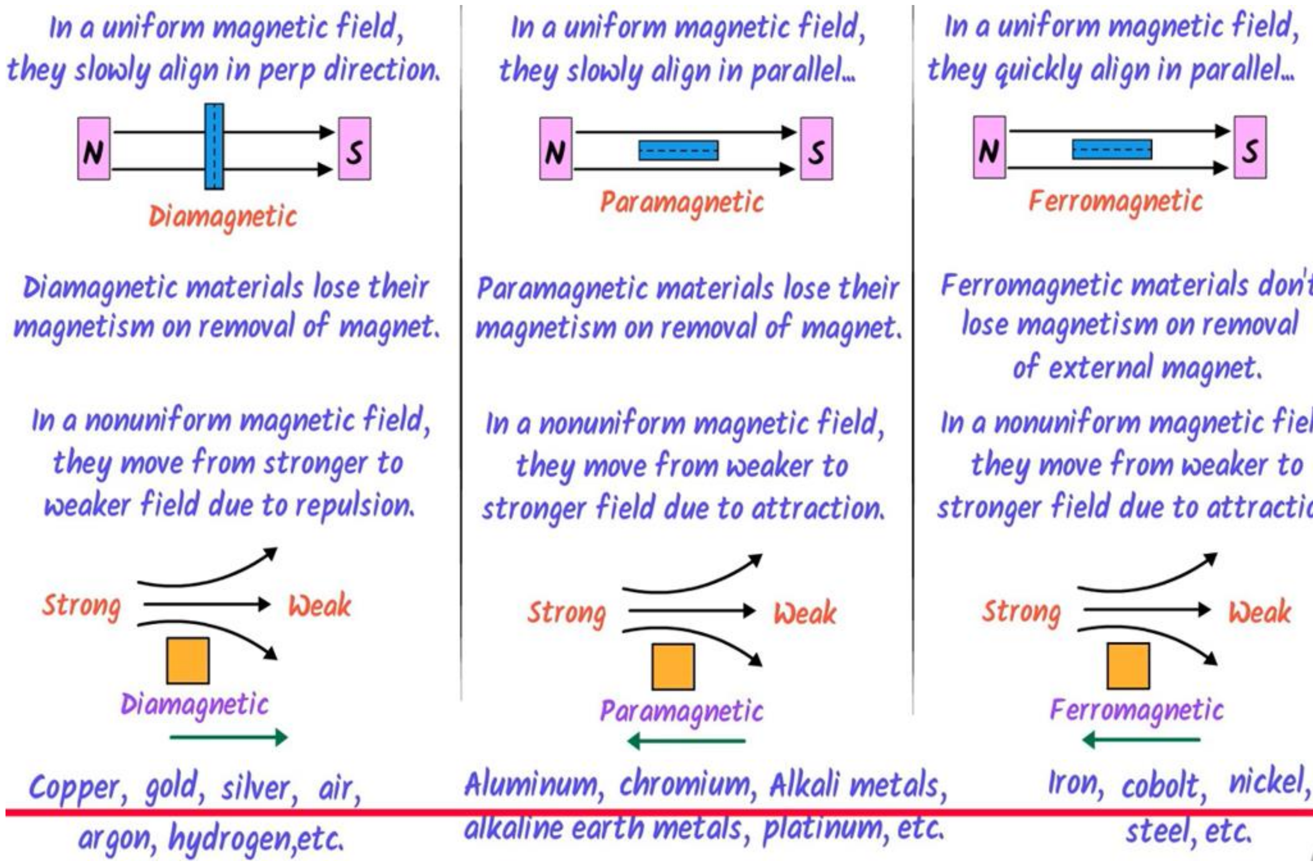


Magnetic materials can be grouped into three types based on how they behave when placed near a magnet.

NON-MAGNETIC MATERIALS:

This is a material that cannot be attracted or repelled by a magnet.

Examples include: Plastic, Rubber, Paper, Copper, Brass, Leather, Wood etc.

POLES OF A MAGNET:

A pole of a magnet is a region on a magnet where the magnetic force is strongest.

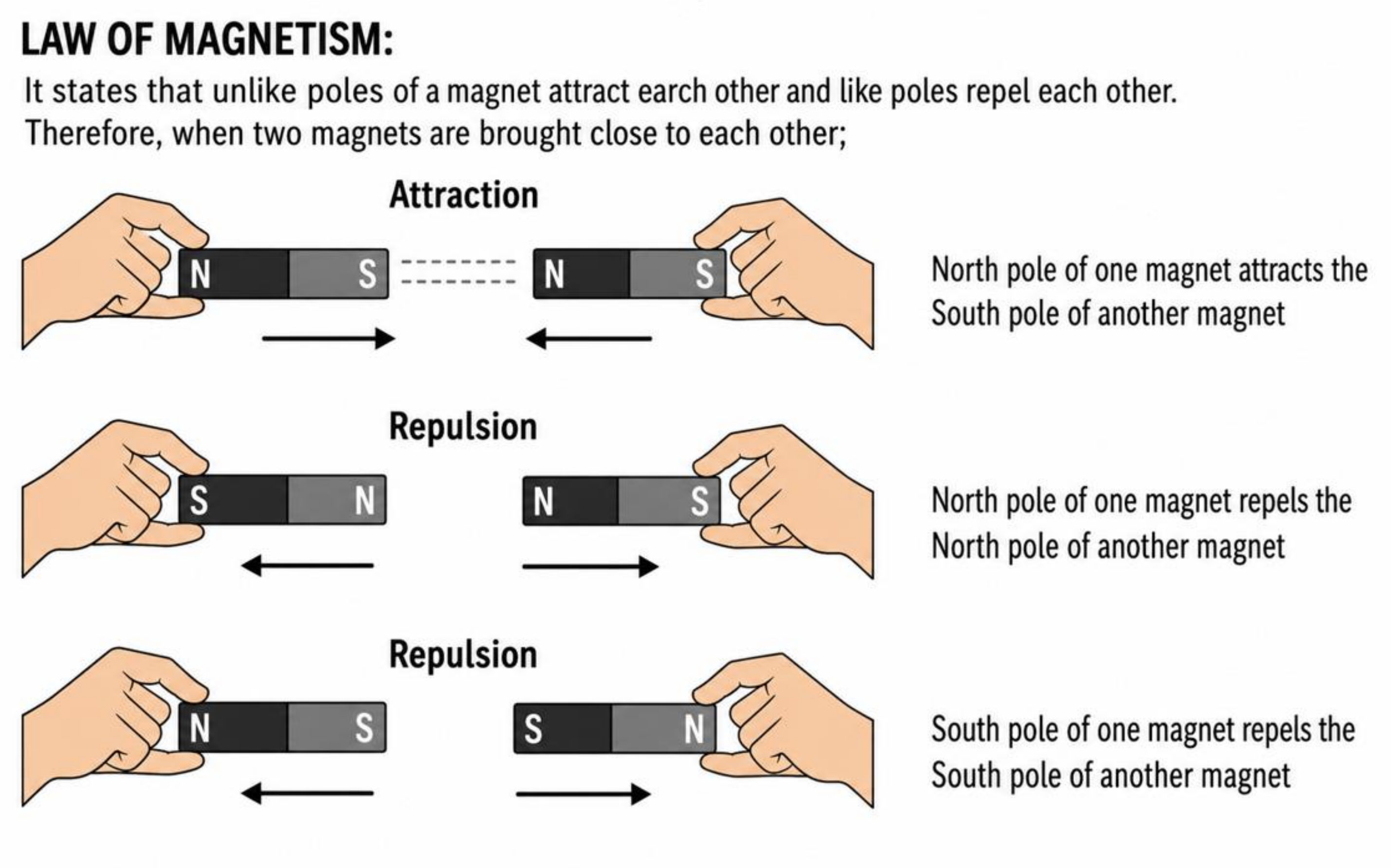
Poles of a magnet are found at the ends of a magnet and they always occur in pairs of equal strength.Every magnet has two poles namely:

North Pole

South Pole.

Note:

When a magnet is broken into two or more pieces, each broken piece will still have a North pole and South pole. Therefore, each broken piece is a complete magnet.

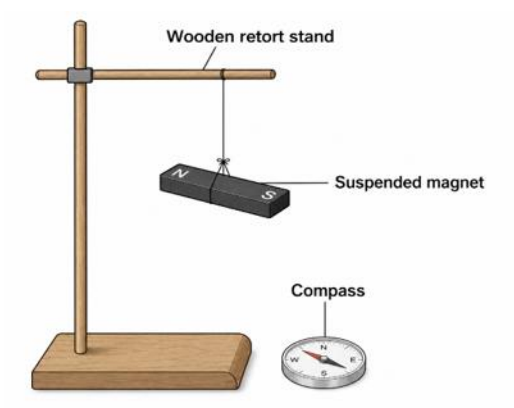


HOW TO DETERMINE THE POLES OF A MAGNET

Method 1: SUSPENSION METHOD

Equipment’s needed: retort stand. a piece of thread, bar magnet with unknown poles, Plotting compass

Experimental set up



Procedure:

(a) A thread is tied at the midpoint of the bar magnet.

(b) Bar magnet is suspended on the retort stand using a thread.

(c) the bar magnet is left to swing freely until it settles (comes to rest).

(d) A compass is places on a flat surface and observe the direction in which the poles of the bar magnet are facing.

Observation:

The bar magnet will come to rest, with one end pointing towards the Earth's magnetic North and the other end pointing towards the Earth's magnetic South (It rests in North-South direction).

Conclusion:

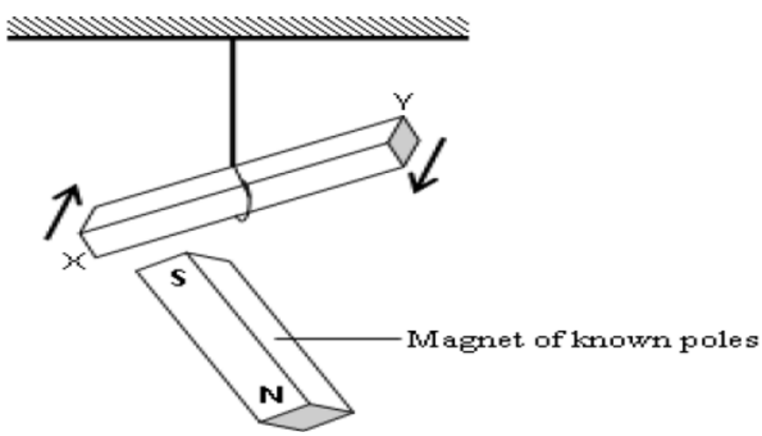
The end of the magnet that points toward the Earth's magnetic North is the South pole of the magnet.

The end that points toward the Earth's magnetic South is the North pole of the magnet.

Note:

The compass needle always points towards the Earth's magnetic North, which helps us to identify the poles of the magnet.

(b) Using a magnet of known poles



Procedure:

(e) a thread is tied at the midpoint of the bar magnet with unknown poles.

(f) bar magnet (with unknown poles) is suspended on the retort stand using a thread.

(g) The bar magnet is left to swing freely until it settles (comes to rest).

(h) North pole of the magnet with known poles is brought close to one end of the suspended magnet with unknown poles.

(i) Observe how the two magnets behave when brought close to each other.

Observation and conclusion:

If the two magnets attract, then the close poles of the two magnets are unlike poles. This means the end of the magnet with unknown poles is the South pole because it is attracted to the North pole of the magnet with known poles.

If the two magnets repel, then the close poles of the two magnets are like poles. This makes the end of the magnet with unknown poles the North pole because it is repelled by the North pole of the magnet with known poles.

PROPERTIES OF MAGNETS:

1.Attractive property – Magnets attract magnetic materials such as iron, nickel, and cobalt.

2.Poles – Every magnet has two poles: north and south.

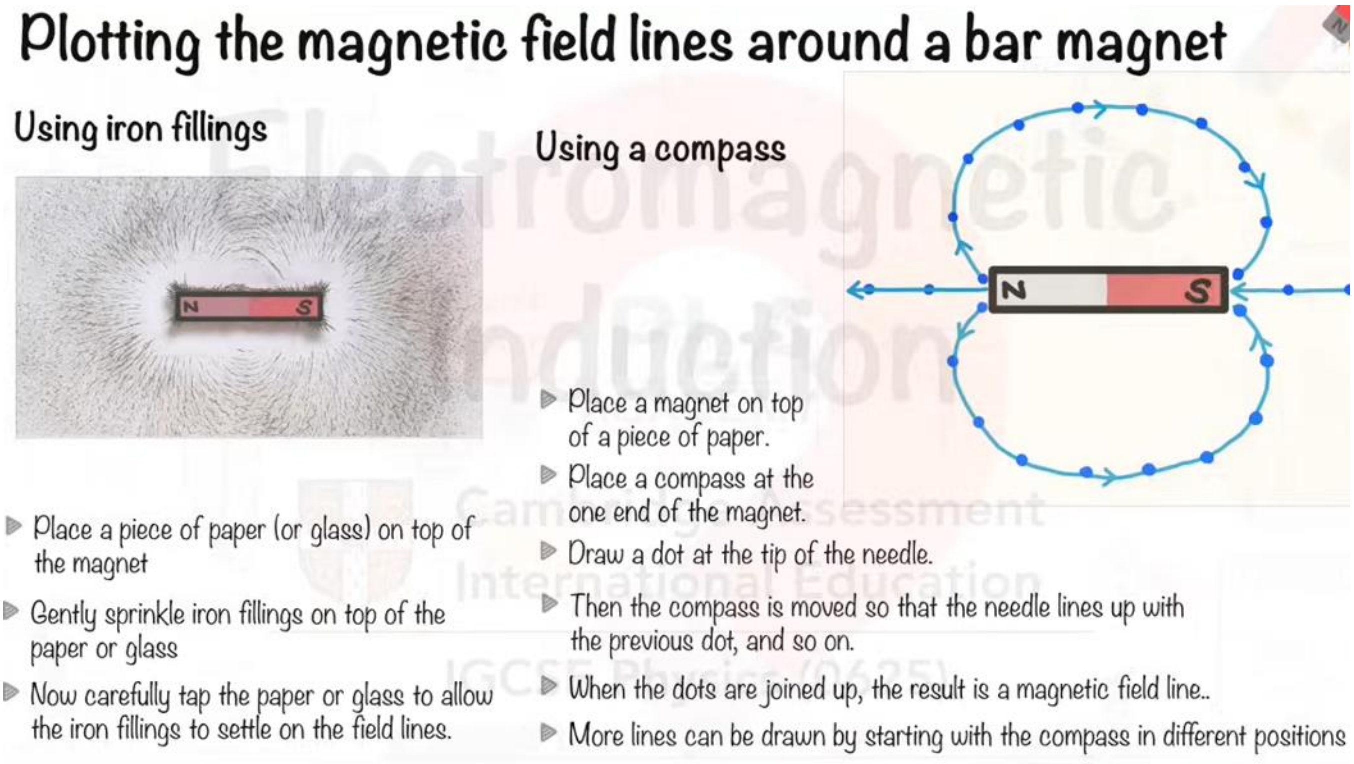
3.Like and unlike poles – Like poles repel each other, while unlike poles attract.

4.Directive property – A freely suspended magnet always aligns itself in the north–south direction.

5.Magnetism is strongest at the poles – The force of attraction is greatest at the ends of the magnet.

6.Induction – A magnet can induce magnetism in another magnetic material.

7.Poles cannot exist alone – If a magnet is cut, each piece still has both north and south poles.



Advantages of using the method of iron filings

- ✓ It clearly reveals the shape and pattern of magnetic field lines around a magnet.
- ✓ It helps to show where the magnetic field is strongest (at the poles) and weakest.
- ✓ It provides a visual and easy-to-understand representation of an invisible magnetic field.
- ✓ It can be used for different magnet shapes (bar magnets, horseshoe magnets, etc.).
- ✓ It is simple, quick, and inexpensive to perform in experiments

Disadvantages of using the method of iron filings

- ✓ The direction of the field is not indicated
- ✓ Cannot be used for weak field

MAGNETISATION

Magnetization is the process of making a magnet from a magnetic material.

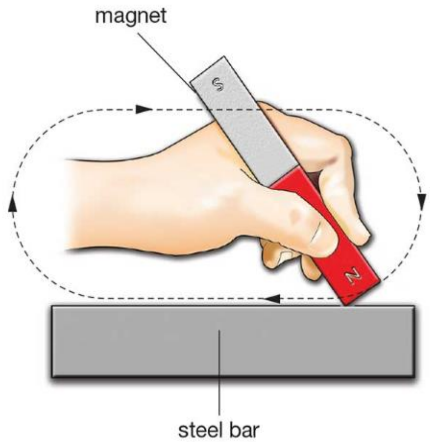
During this process, the dipoles (tiny atomic magnets) of a ferromagnetic material like iron or steel are arranged to face in the same direction.

METHODS OF MAGNETISATION:

There are four common methods of magnetizing a magnet and they include:

1. Single touch/stroke method
2. Double or divided touch/stroke method
3. Electrical method
4. Induction method.

SINGLE TOUCH/STROKE METHOD



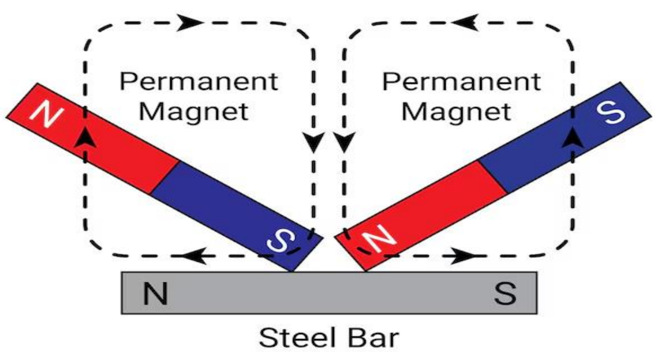
Procedure:

a) One end of a magnet was moved along the surface of the steel bar in one direction.
b) The magnet was lifted high at the end of the stroke to avoid reversing the magnetization.
c) The stroking process was repeated several times in the same direction.
d) The end where the magnet finished stroking acquired a pole opposite to that of the stroking pole of the magnet.

This method produces a magnet with one pole nearer to the end compared to the other pole.

2. DOUBLE OR DIVIDED TOUCH METHOD

Two magnets are used to magnetize a steel bar simultaneously.



Procedure:

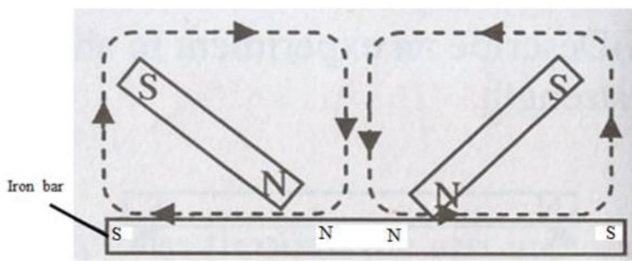
Two magnets are placed with opposite poles at the center of the bar.

The magnets are then Moved outward repeatedly from the center to the ends.

Both ends become magnetized.

Consequent poles

These are two similar poles formed at the ends and the middle of the iron bar that has been magnetized by double touch method using similar poles.



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.

Determining the polarity of the magnet produced.

The polarity of the magnet produced depends on the direction of the current at the ends of the solenoid.

It can be established by using one of the following methods:

(i) Using the direction of flow of current.

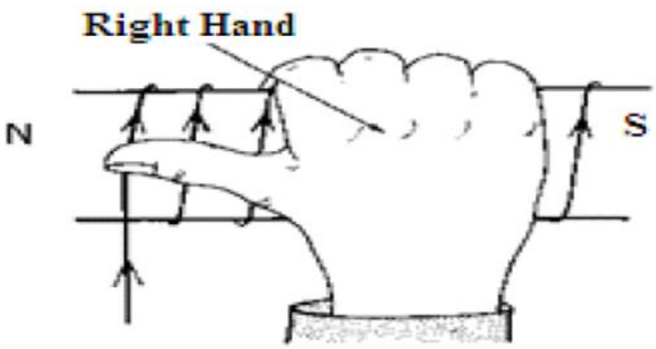
Look at the ends of the solenoid;

If the current is flowing in a clockwise direction, that will be a South Pole.

If it is flowing in an anti-clockwise direction, then that will be the North Pole.

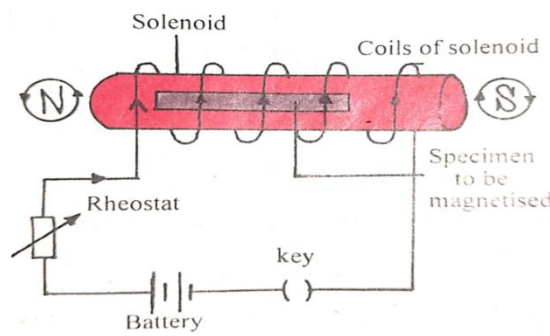
(ii) Using the Right-Hand Grip Rule.

Grip the solenoid such that the fingers point in the direction of current in the solenoid. Then, the thumb points in the North pole.



3. ELECTRICAL METHOD (USING CURRENT)

A coil (solenoid) carrying electric current is used to magnetize a soft iron or steel core.



Procedure:

Wind insulated wire around a soft iron rod.

Connect to a battery.

When current flows, the iron rod becomes magnetized.

4. INDUCTION METHOD

A magnetic material becomes magnetized when placed near a strong magnet without contact.

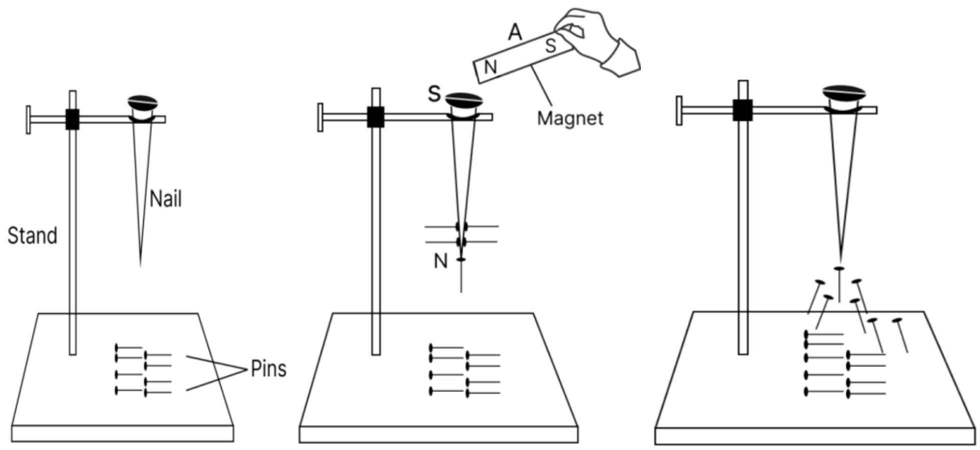
Procedure:

Place a steel rod near a magnet.

The magnetic field induces magnetism in the rod

What is magnetic induction? Explain with the help of a diagram

When a piece of iron is placed nearby (or brought near) a magnet, it acts as a magnet i.e., it acquires the properties of a magnet temporarily. But as soon as the magnet is removed, the iron piece no longer remains a magnet. This process is called magnetic induction.



Procedure

a) An iron nail was clamped vertically on a stand.
b) Iron pins were spread on the base below the nail.
c) It was observed that the pins did not move towards the nail.
d) The strong magnet was brought near the head of the nail as shown in fig 2
e) The iron pins began to cling to the nail, showing that the nail had become magnetized by induction.
f) The magnet was then removed from the nail as shown in fig 3
g) The iron pins fell off, showing that the nail had lost its magnetic property.

Conclusion

The iron nail became a temporary magnet by magnetic induction when placed near a magnet, but lost its magnetism when the external magnet was removed.

Note: Magnets are the Backbone of Medical Imaging

MRI (Magnetic Resonance Imaging): This is the classic and most important use. MRI uses strong magnetic fields and radio waves to create high-resolution images of the inside of your body. It's a cornerstone of modern diagnosis.

MPI (Magnetic Particle Imaging): A newer technology that directly detects magnetic nanoparticles injected into the body. It allows for super-sensitive cell tracking and targeted imaging.

Better imaging contrast: Magnetic nanoparticles—especially SPIONs (superparamagnetic iron oxide nanoparticles)—are used as contrast agents in MRI to significantly improve diagnostic accuracy.

Magnets Enable Non-Invasive and Precision Treatments

TMS (Transcranial Magnetic Stimulation): This is a completely non-invasive neuromodulation technique. It uses magnetic fields to stimulate specific areas of the brain. TMS is used to treat depression, anxiety, insomnia, and is also widely used in stroke recovery.

MHT (Magnetic Hyperthermia): A cutting-edge cancer treatment. Magnetic nanoparticles are delivered into a tumor, and an external alternating magnetic field heats them up to 42–46°C. That heat "cooks" the cancer cells with very little damage to healthy tissue.

Targeted drug delivery: Drugs are loaded into magnetic carriers, and an external magnetic field guides them to the disease site before release. This boosts the drug concentration where it's needed and reduces side effects elsewhere. The Suzhou Institute of the Chinese Academy of Sciences has developed a liver cancer targeting system that achieves 90% drug accumulation in the tumor.

Magnetically controlled microrobots: This is one of the fastest-growing areas. These tiny robots, about the size of a grain of sand, are controlled by magnets and can navigate precisely inside the body to deliver drugs. A team at ETH Zurich has already achieved over 95% precision in drug delivery in animal studies.

Transcranial Magnetic Stimulation

Magnets Are Powerful Surgical Assistants

Changing minimally invasive surgery: Using magnetic force instead of traditional instruments means smaller incisions, less pain, and faster recovery. The FDA has already approved a magnetic minimally invasive surgical robot platform.

Magnetic anchoring and traction: In laparoscopic surgery, magnets outside the body attract magnetic instruments inside the body to pull tissue out of the way. This reduces the number of abdominal incisions needed.

Magnetic anastomosis: Two magnets attract each other across tissue, compressing it until it heals and forms a connection. This is especially useful in complex surgeries like digestive tract reconstruction. Some call it "smart anastomosis."

Removing foreign objects: Rare earth magnets can be used to remove metal objects that accidentally get into the body—minimally invasively. This is especially helpful for children.

What Kinds of Magnets Make All This Possible?

After reading about all these medical applications, you might be wondering: what actual magnet products are behind them? The core materials fall into three main categories: permanent magnets, soft magnetic materials, and magnetic nanomaterials.

SOFT MAGNETIC MATERIALS: Soft magnetic materials are defined as materials that can be easily magnetized and demagnetized, requiring only small energy for these processes.

Properties: These materials have high permeability, low coercive force, low hysteresis loss, small remanent induction, and high saturation magnetization.

Examples: Examples include pure iron, silicon iron alloys, and nickel iron alloys (Hypernik), each with specific uses based on their properties.

Applications: Soft magnetic materials are used in various AC and DC applications such as transformers, electric motors, magnetic shielding, and electromagnetic pole-pieces

Hysteresis Loop: is a closed curve (graphical representation) obtained when magnetic flux density (B) is plotted against magnetizing force (H) for a magnetic material during magnetization and demagnetization. It shows that the magnetism of a material depends not only on the present magnetic field but also on its previous magnetic state.

Hysteresis loops are central to characterizing magnetic cores in transformers, ferroelectric capacitors, and piezoelectric materials. They guide material selection by balancing coercivity and energy efficiency. In control systems, hysteresis is deliberately introduced to avoid oscillations and enhance stability

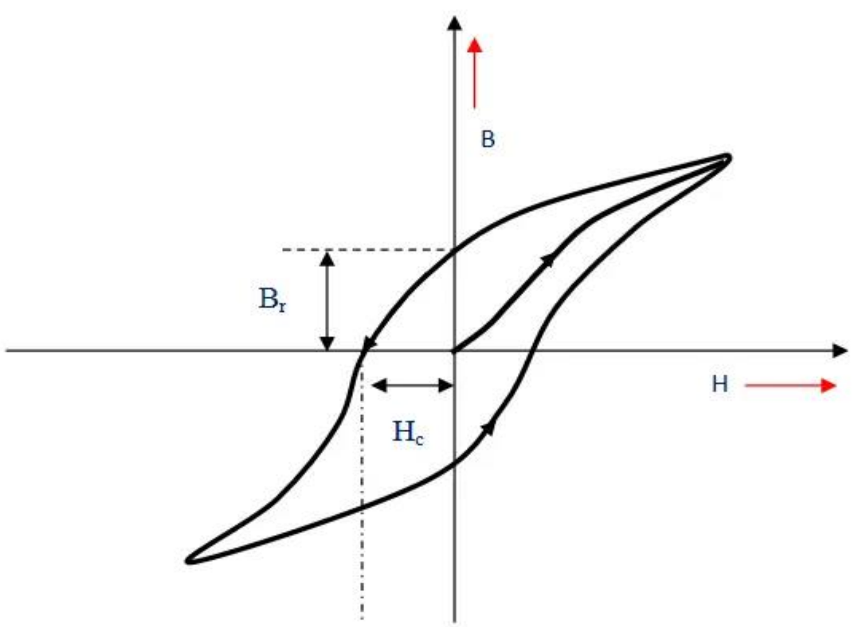


Figure 1

Remanent Induction:

It is actually the value of induction which residue, once the material is magnetized and then the magnetizing field is decreased to zero. It is denoted by Br.

Coercive Force:

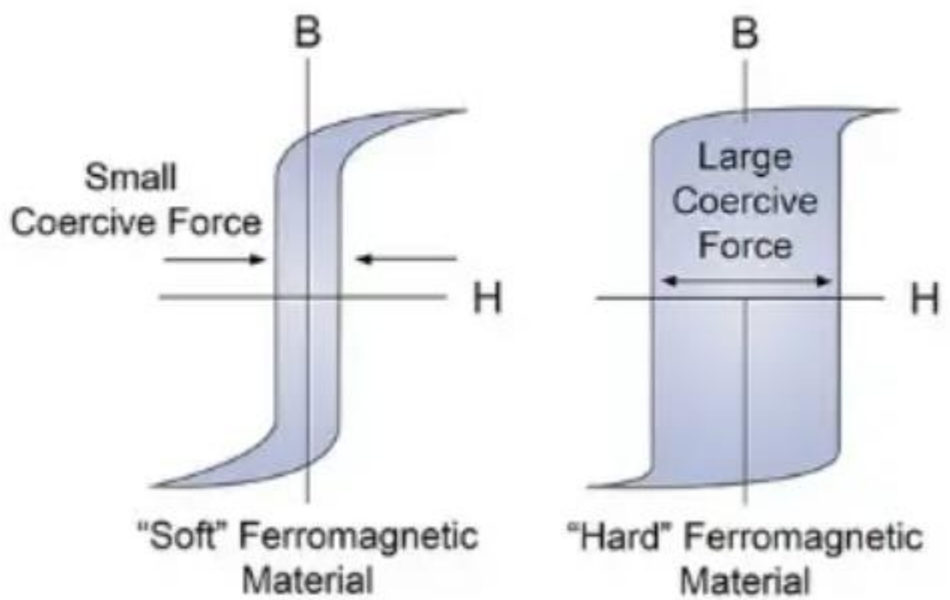
It is the amount of negative magnetic field which is essential to decrease the remanent induction to zero. It is denoted by Hc.

The total area of the hysteresis loop = the energy which is dissipated when a material of unit volume is magnetized during a cycle of operation.

Growth of domains and rotation of domains take place during magnetization. Both can be reversible or irreversible.

Magnetic materials are mainly classified (based on the magnitude of coercive force) into two- hard magnetic materials and soft magnetic materials,

Soft magnetic materials can be easily magnetized and demagnetized because they require very little energy. Their coercive field is very small, less than 1000 A/m.



HARD MAGNETIC MATERIALS

Hard magnetic materials, also referred to as **permanent magnets,** retain a significant amount of magnetization after an external magnetic field is removed. These materials exhibit high coercivity and high remanence, allowing them to maintain strong magnetic fields over time and under adverse conditions.

They are typically used in applications where a persistent magnetic field is required, such as in electric motors, generators, magnetic sensors, and consumer electronics. Hard magnets are also integral to renewable energy systems, such as wind turbines, were long-term magnetic stability

EXAMPLES OF HARD MAGNETIC MATERIALS

1.NdFeB (Neodymium-Iron-Boron)

These rare-earth magnets are among the strongest known, offering high energy products. They are widely used in compact, high-efficiency motors and renewable energy applications.

2.SmCo (Samarium-Cobalt)

Known for their excellent thermal stability and corrosion resistance, SmCo magnets are used in aerospace and other high-temperature environments.

3.AlNiCo (Aluminum-Nickel-Cobalt)

Although weaker than rare-earth magnets, AlNiCo alloys perform well at high temperatures and are used in sensors, pickups, and instrumentation.

4.Hard Ferrites (Ceramic Magnets)

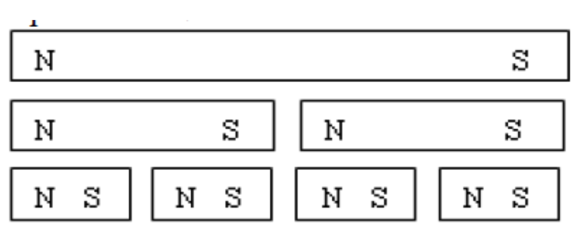
Composed of iron oxide and barium or strontium carbonate, hard ferrites are inexpensive, corrosion-resistant, and widely used in speakers, motors, and magnetic assemblies

Conclusion

Both soft and hard magnetic materials are foundational to modern technology. Soft magnetic materials enable efficient energy transfer and control in variable magnetic fields, particularly in AC systems. Hard magnetic materials provide strong, stable magnetic fields in DC applications where long-term performance is essential.

DOMAIN THEORY OF MAGNETISM

The domain theory of magnetism states that magnetic materials are made up of many tiny regions called magnetic domains. Within each domain, the atomic magnets are aligned in the same direction. In an unmagnetized material, the domains point in different directions, so their magnetic effects cancel out. When the material is magnetized, many domains align in one direction, producing a strong magnetic field.

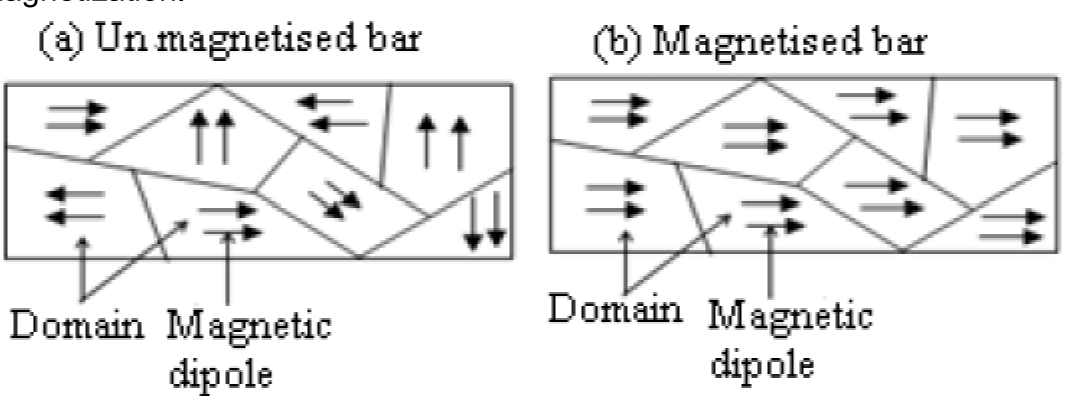


ORIGIN OF DOMAINS:

Magnetic domains originate from the interaction of atoms inside ferromagnetic materials such as iron, cobalt, and nickel. Due to the alignment of electron spins and magnetic moments, neighboring atoms tend to orient in the same direction. To reduce internal magnetic energy, the material naturally divides into small regions called domains, each magnetized in a particular direction. These domains are separated by thin boundaries known as domain walls

Summary:

- ✓ Domain theory states that ferromagnetic materials consist of many small regions (domains) with uniform magnetization.
- ✓ Domains form to minimize the total magnetic energy of the material.
- ✓ The origin of domains is due to the interplay of exchange energy, magnetostatic energy, anisotropy energy, and domain wall energy.
- ✓ When magnetized, domains aligned with the external field grow, causing net magnetization.



APPLICATIONS OF THE DOMAIN THEORY OF MAGNETISM :

1.**Making Permanent Magnets:** The theory explains how magnetic domains align to produce strong magnets used in speakers, electric bells, and refrigerator doors.

2.**Electric Motors and Generators**: Motors and generators work because magnetic domains in iron cores become aligned, producing strong magnetic fields for energy conversion.

3.**Transformers:** Soft iron cores in transformers are designed using domain theory so that domains align and realign easily, reducing energy loss.

4.**Data Storage Devices:** Hard disks and magnetic tapes store information by arranging magnetic domains in different directions to represent data.

5.**Magnetic Cranes**: Electromagnets used in scrapyards lift heavy iron objects by magnetizing iron through domain alignment.

6.**Medical Equipment**: Devices such as MRI scanners depend on strong magnetic fields produced through controlled magnetization of materials.

7: **Compass Needles**: The domains in a compass needle remain aligned, allowing it to point towards the Earth's magnetic field direction.

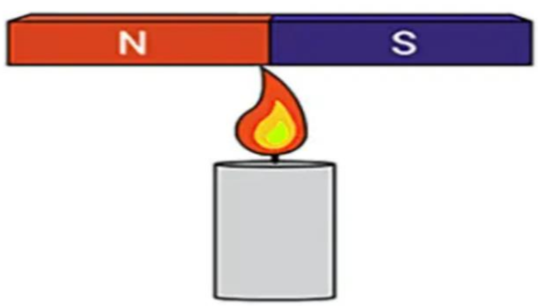
8.**Magnetic Locks and Sensors**: Many security systems and automatic doors use magnetic materials whose behavior is explained by domain theory.

DEMAGNETIZATION

Demagnetization is the process by which a material loses its magnetic properties or the alignment of its magnetic domains. It can occur naturally through heat, shock, or opposing magnetic fields, or be done intentionally to remove unwanted magnetism from tools, instruments, or media.

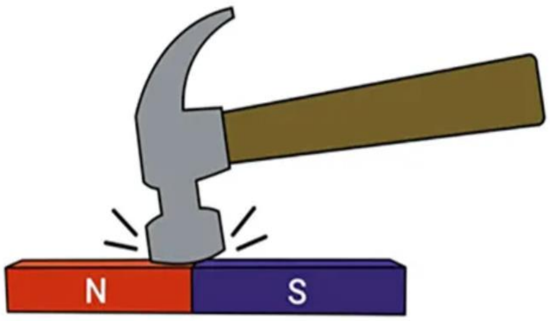
METHODS OF DEMAGNETIZATION

1.Heating a Magnet



When the ferromagnetic material is heated to above the Curie temperature (the temperature at which the magnetic domains inside the magnet lose their arrangement direction) This method is mainly used for permanent removal of magnetism from large magnets or components because excessive heating permanently weakens the material and it cannot fully regain its original magnetic strength even after remagnetization.

2.Hammering or Mechanical Shock



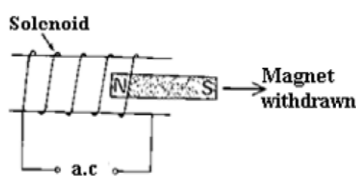
Striking a magnet disturbs the arrangement of domains, weakening the magnet.

3. Electrical Degaussing (Alternating Current Method)

Electrical Degaussing is the process of removing or reducing unwanted magnetism from a magnetic material by using an alternating electric current.

In this method, the magnetized object is placed inside a coil connected to an alternating current (A.C.) supply. The changing magnetic field produced by the A.C. repeatedly reverses the alignment of magnetic domains until they become randomly arranged, causing the material to lose its magnetism.

Diagram



Procedure:

A solenoid was connected to an alternating current (a.c.) power supply.

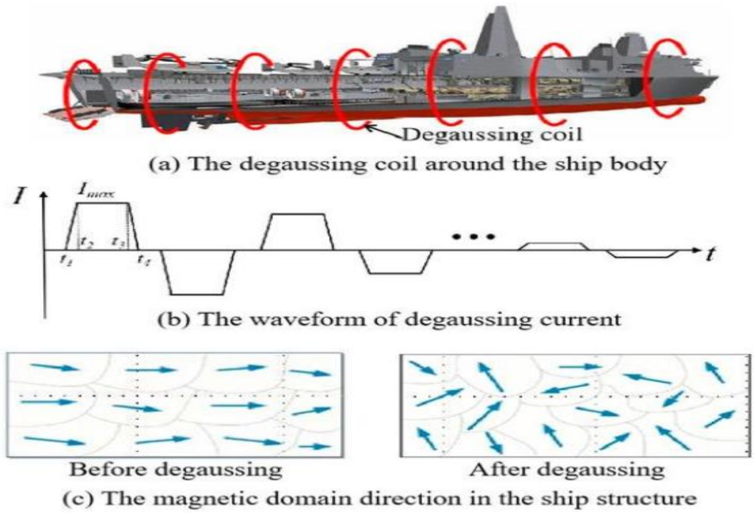
The magnet was placed inside the solenoid.

The alternating current was switched on to produce a changing magnetic field inside the solenoid.

The magnet was then withdrawn slowly from the solenoid while the a.c. supply remained on.

The changing magnetic field disturbed the alignment of the magnetic domains in the magnet.

The magnet gradually lost its magnetism.



Key Facts

- ✓ **Purpose**: To neutralize residual magnetism in metal objects.
- ✓ **Primary application**: Magnetic signature reduction for naval vessels.
- ✓ **Method:** Controlled alternating current (AC) field demagnetization.
- ✓ **Origins**: Developed during World War II for naval protection.
- ✓ **Common devices:** Degaussing coils, wands, and demagnetizers

Applications of Electrical Degaussing

- ✓ Demagnetizing tools and machine parts.
- ✓ Erasing data from magnetic tapes and hard disks.
- ✓ Reducing magnetic interference in electronic equipment.
- ✓ Protecting ships and devices from unwanted magnetic fields.

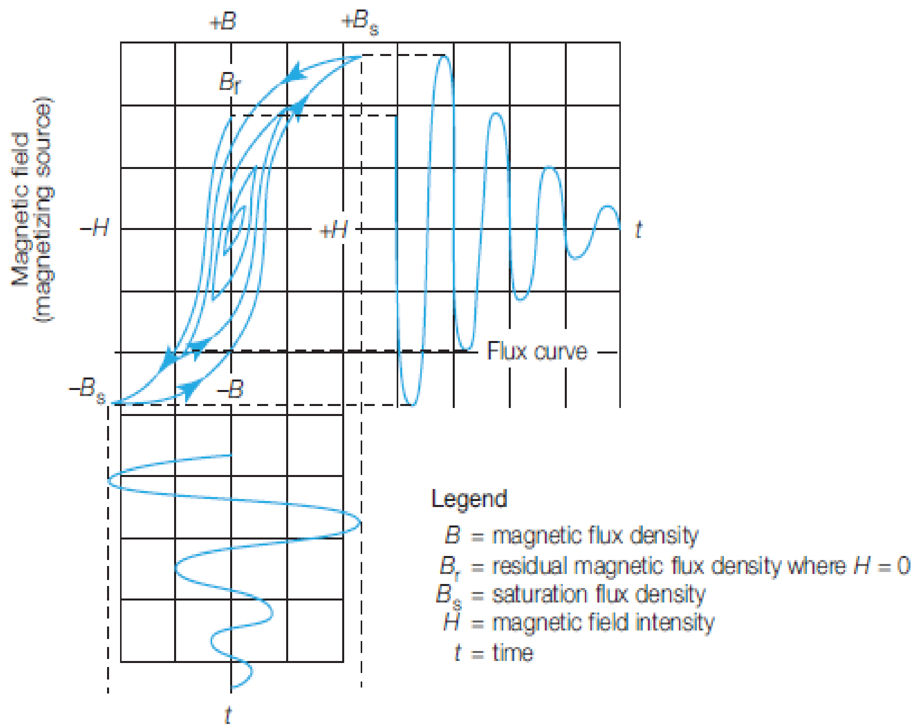
4.Improper Storage

Improper storage of a magnet, such as keeping it without a keeper or exposing it to careless handling, causes the magnetic domains to lose their proper alignment gradually. As a result, the magnet becomes weaker and may eventually lose much of its magnetism.

Note: Devices based on Magnetization and Demagnetization are important because they are used in:

- ✓ Electric motors and generators.
- ✓ Transformers and electromagnets.
- ✓ Magnetic cranes for lifting scrap metal.
- ✓ Speakers, microphones, and electric bells.
- ✓ Data storage devices such as hard disks and tapes.

- ✓ Medical equipment like MRI machines.
- ✓ Removing unwanted magnetism from tools and machines.



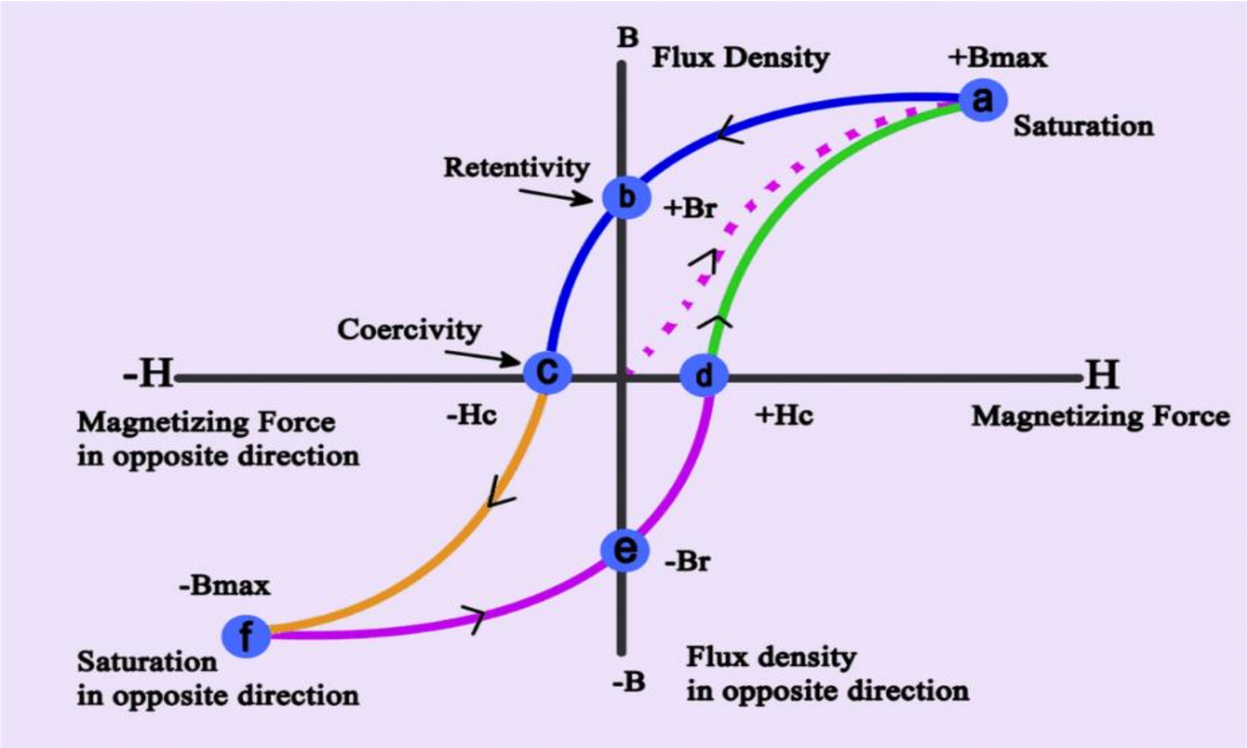
Applications of Demagnetization

1. Erasing data from magnetic tapes and hard disks.
2. Removing unwanted magnetism from tools and machines.
3. Preparing magnetic materials for remagnetization.
4. Reducing magnetic interference in electronic equipment.

MAGNETIC SATURATION

Magnetic saturation is the physical limit at which a magnetic material cannot further increase its internal magnetization despite increasing the external magnetic field. It marks the maximum alignment of atomic magnetic dipoles and defines the upper bound of a material’s magnetic response, critical to the operation of transformers, motors, and other electromagnetic devices.

Magnetic saturation appears on a B–H or **magnetization (hysteresis) curve** as a "knee" where flux density (B) ceases to rise proportionally with the magnetizing field (H). In practice,



APPLICATIONS OF MAGNETIC SATURATION

1. **Transformers:** Transformer cores are designed to avoid saturation for efficient energy transfer.
2. **Electric Motors and Generators:** Magnetic saturation helps engineers determine the operating limits of motor and generator cores.
3. **Electromagnets:** It is used in designing strong electromagnets for cranes, relays, and electric bells.
4. **Magnetic Amplifiers:** Saturation is used to control electric current in magnetic amplifier circuits.
5. **Industrial Magnetic Devices:** Magnetic saturation is important in sensors, inductors, and magnetic recording systems to improve performance and prevent energy loss.