UNIT – II MAGNETIC MATERIALS

PART – A

1. Define magnetic induction.

It is the imaginary lines of forces which are supposed to travel from South Pole to North Pole inside the magnet.

2. Define magnetic dipole.

A system having two opposite magnetic poles separated by a distance'd' is called as a magnetic dipole.

3. Define magnetic dipole moment.

Magnetic dipole moment of a magnet is the product of magnetic pole strength and the distance between the poles.

4. What is Bohr magneton?

The orbital magnetic moment and the spin magnetic moment of an electron in an atom can be expressed in terms of atomic unit of magnetic moment called Bohr magneton.

$$1 \text{ Bohr Magneton} = \frac{e\hbar}{2m} \Rightarrow \mu B \Rightarrow 9.27\times10^{-24}\, Am^2$$

5. Define magnetic permeability.

The ratio between the magnetic flux density (B) and the magnetic field intensity (H) is called magnetic permeability.

$$\mu = \frac{B}{H}$$

6. Define magnetic susceptibility.

The ratio between intensity of magnetization (I) and the magnetic field intensity (H) is called magnetic susceptibility.

$$\chi_m = \frac{I}{H}$$

7. What is domain in ferromagnetic material?

The group of atomic dipoles organized into tiny bounded regions in the ferromagnetic materials is called magnetic domains.

8. Define domain walls?

The group of atomic dipoles organized into tiny bounded regions in the ferromagnetic materials is called magnetic domains. The boundaries separating the domains are called domain walls.

9. What is domain theory of ferromagnetism?

The group of atomic dipoles organized into tiny bounded regions in the ferromagnetic materials is called magnetic domains. The boundaries separating the domains are called domain walls. When an external magnetic field is applied to a ferromagnetic material, the domains align themselves. It produces a large net magnetization.

10. List out the energies involved in the domain theory of ferromagnetism.

(i) Exchange energy
(ii) Anisotropic energy
(iii) Domain wall energy
(iv) Magnetostrictive energy

11. What is meant by Hysteresis of a magnetic material?

Hysteresis means lagging behind.

The phenomenon of lagging of magnetic 'induction (B) behind the magnetic field (H) when a cycle of magnetization is applied to a ferromagnetic material is called Hysteresis.

12. Define Hysteresis loss.

In the process of magnetization of a ferromagnetic material in a cycle, there is expenditure of energy. This energy is not recoverable and occurs a loss of energy in the form of heat. This loss is hysteresis loss.

PART – B

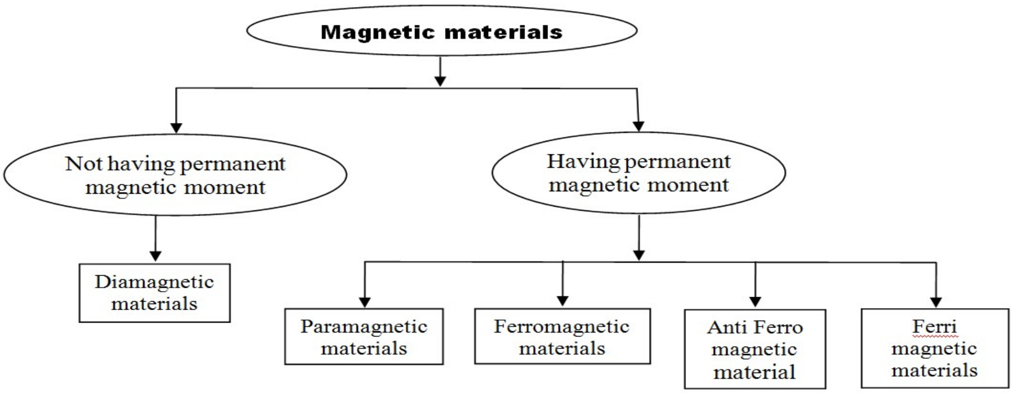
MAGNETIC MATERIALS

1. What are magnetic materials? How are they classified? Explain each of them.

Magnetic materials

Magnetic materials are the materials which can be made to behave as magnets. They can be easily magnetized when it is kept in a magnetic field.

Classification (or) Types



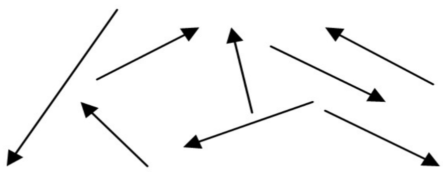
Diamagnetic materials

- In these materials, there is no electron spins.
- They have equal and opposite electron spins.
- Hence the spin moments are almost paired.
- Thus the net magnetic moment is zero.
- They do not exhibit magnetization in the absence magnetic field.
- When an external magnetic field is applied, the electron spins align perpendicular to the field direction.
- These magnetic materials are called weak magnets.

Properties

- These materials repel magnetic lines of force.
- They are independent of temperature.
- Susceptibility is negative.
- Permeability is less than 1.
- No permanent dipole moment.
- When the temperature is less than critical temperature, diamagnetic material becomes normal material.
- **Examples**: Gold & Germanium.

Paramagnetic materials



Random Alignment of Dipoles

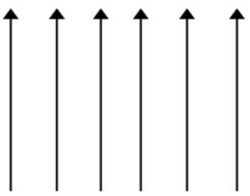
- In these materials, the electron spins are randomly aligned.
- They have number of unequal electron spins.
- They have some unpaired electron spins.
- Hence the net magnetic moment will not be zero.
- They exhibit less magnetization in the absence magnetic field.
- When an external magnetic field is applied, the electron spins align towards the field direction.

- These magnetic materials are called strong magnets.

Properties

- These materials attract magnetic lines of force.
- They are dependent of temperature.
- Susceptibility is positive.
- Permeability is greater than 1.
- They have permanent dipole moment.
- When the temperature is less than critical temperature, paramagnetic material becomes diamagnetic material.
- **Examples**: Platinum & Chromium.

Ferromagnetic materials



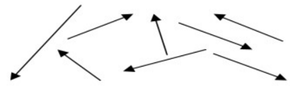
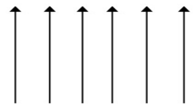
Parallel alignment of dipoles

- In these materials, the electron spins are aligned in parallel manner.
- They have more number of unequal electron spins.
- They have more number of unpaired electron spins.
- Hence the net magnetic moment is zero.
- They exhibit magnetization even in the absence magnetic field.
- When an external magnetic field is applied, the electron spins align towards the field direction.
- These magnetic materials are called very strong magnets.

Properties

- These materials strongly attract magnetic lines of force.
- They are dependent of temperature.
- Susceptibility is positive.
- Permeability is very much greater than 1.
- They have permanent dipole moment.
- When the temperature is greater than critical temperature, ferromagnetic material becomes paramagnetic material.
- **Examples**: Nickel & Cobalt.

2. Distinguish between dia, para, ferromagnetic materials.

Diamagnetic materials	Paramagnetic materials	Ferromagnetic materials
There is no electron spins.	The electron spins are randomly aligned.  Random Alignment of Dipoles	the electron spins are aligned in parallel manner.  Parallel alignment of dipoles
They have equal and opposite electron spins.	They have number of unequal electron spins	They have more number of unequal electron spins.
The spin moments are almost paired.	They have some unpaired electron spins.	They have more number of unpaired electron spins.
The net magnetic moment is zero.	The net magnetic moment will not be zero.	The net magnetic moment is zero.
They do not exhibit magnetization in the absence magnetic field.	They exhibit less magnetization in the absence magnetic field.	They exhibit magnetization even in the absence magnetic field.
When an external magnetic field is applied, the electron spins align perpendicular to the field direction.	When an external magnetic field is applied, the electron spins align towards the field direction.	When an external magnetic field is applied, the electron spins align towards the field direction.
These magnetic materials are called weak magnets.	These magnetic materials are called strong magnets.	These magnetic materials are called very strong magnets.
These materials repel magnetic lines of force.	These materials attract magnetic lines of force.	These materials strongly attract magnetic lines of force.
They are independent of temperature.	They are dependent of temperature.	They are dependent of temperature.
Susceptibility is negative.	Susceptibility is positive.	Susceptibility is positive.
Permeability is less than 1.	Permeability is greater than 1.	Permeability is greater than 1.
No permanent dipole moment.	They have permanent dipole moment.	They have permanent dipole moment.
When the temperature is less than critical temperature, diamagnetic material becomes normal material.	When the temperature is less than critical temperature, paramagnetic material becomes diamagnetic material.	When the temperature is greater than critical temperature, ferromagnetic material becomes paramagnetic material.
Examples: Gold & Germanium.	**Examples**: Platinum & Chromium.	**Examples**: Nickel & Cobalt.

3. What is ferromagnetism? Explain Weiss theory (domain theory) of ferromagnetism and the types of energy involved in the process of domain growth in detail.

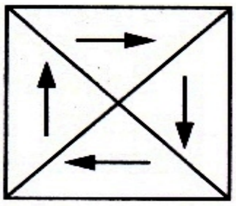
Ferromagnetism

Ferromagnetism is due to more number of unpaired electrons. Certain metals like iron (Fe), cobalt (Co), nickel (Ni) exhibit magnetization even in the absence of magnetic field. This is called spontaneous magnetization. It makes the magnetic moments align parallel to each other. This phenomenon is called **ferromagnetism.**

Domain theory of ferromagnetism

The group of atomic dipoles organized into tiny (small) regions in the ferromagnetic materials is called **magnetic domains**. The boundaries separating the domains are called **domain walls** (or) **Bloch walls**.

In the absence of magnetic field, the domains are randomly oriented. So the net magnetization is zero.



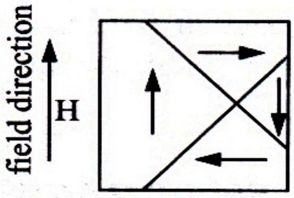
Without field

When a magnetic field is applied to a ferromagnetic material, the domains align themselves. It produces a large net magnetization. It occurs in two ways.

1. By the movement of domain walls
2. By the rotation of domain walls

1. By the movement of domain walls

(i) Movement of domain walls takes place in weak magnetic field.
(ii) When the weak magnetic field is applied, the magnetic moment increases.

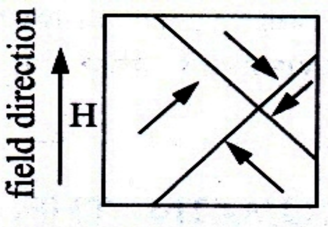


With field (weak)

(iii) Hence the boundary of domains is displaced (moved).
(iv) So the domains grow due to the application of weak magnetic field.

2. By the rotation of domain walls

(i) Rotation of domain walls takes place in strong magnetic field.
(ii) When the strong magnetic field is applied, domain growth is impossible.



With field (strong)

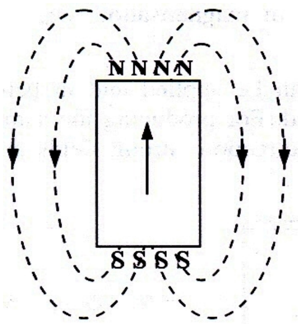
(iii)So rotation of magnetic moment takes place along the direction of applied field.

Energies involved in the domain growth

1. Exchange energy
2. Anisotropic energy
3. Domain wall energy
4. Magnetostrictive energy

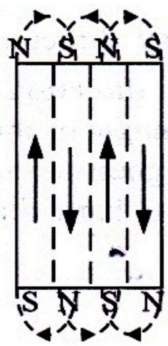
1. Exchange energy

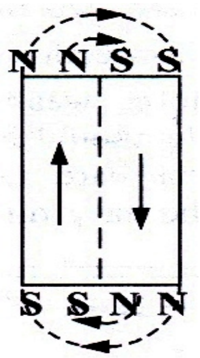
(i) The interaction energy which makes the adjacent dipoles to align themselves is known as **exchange energy**.



(ii) This energy arises from the interaction of electron spin.

(iii) It depends upon the interatomic distance.

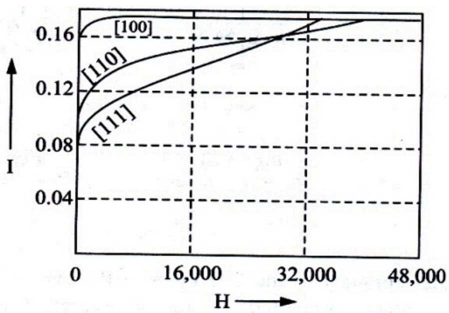




2. Anisotropic energy

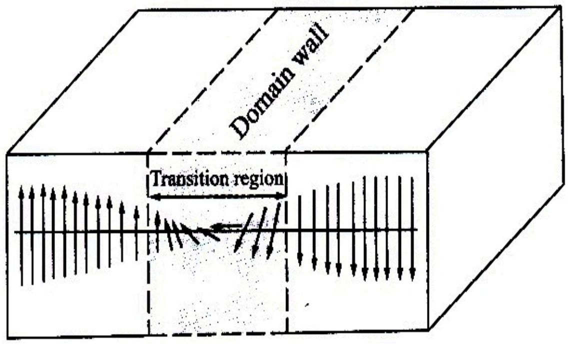
(i) The excess energy required to magnetize the material in hard direction over that required to magnetize the material in easy direction is called **crystalline anisotropic energy**.

(ii) There are two directions of magnetization in ferromagnetic crystals, viz, (a) Easy direction & (ii) Hard direction.



(iii) For example, [100] – Easy direction
[110] – Medium direction
[111] – Hard direction.

3. **Domain wall energy (or) Bloch wall energy**
   (i) **Bloch wall** is a transition layer which separates the adjacent domains magnetized in different directions.
   (ii) When the direction of the spins at the boundary changes gradually, it leads to a **thick Bloch wall**. It is due to exchange energy.



   (iii) When the direction of the spins at the boundary changes suddenly, it leads to a **thin Bloch wall**. It is due to anisotropic energy.

4. **Magnetostrictive energy**
   (i) When the domains are magnetized, there exists in expansion or shrinkage in domains. It produces a change in dimension in the materials. The energy produced in this effect is called **magnetostrictive energy**.
   (ii) The change in dimension depends upon the nature of the material.
   (iii) In Ni – Length decreases & in permalloy – Length increases.

4. Explain the formation of hysteresis in ferromagnetic materials using Domain theory.

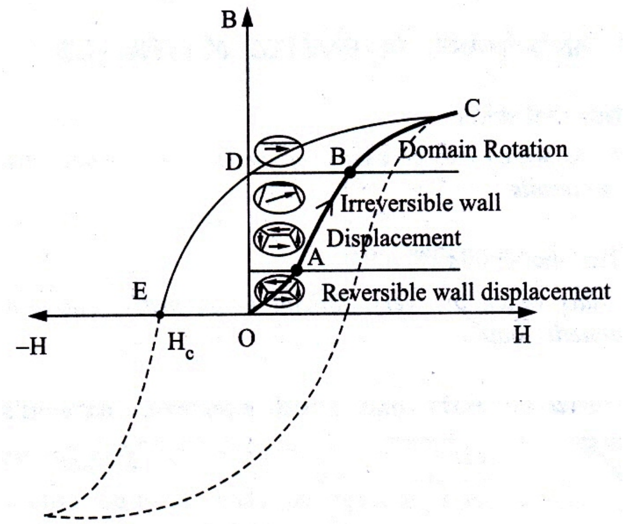
Hysteresis

Hysteresis means **lagging behind**.

The phenomenon of lagging of magnetic 'induction (B) behind the magnetic field (H) when a cycle of magnetization is applied to a ferromagnetic materials is called **Hysteresis**.

Hysteresis loop

The closed curve obtained during the cycle of magnetization of a material is known as **hysteresis loop**.



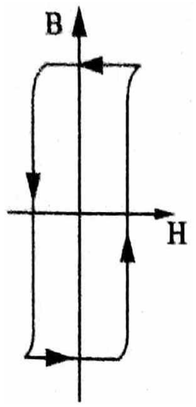
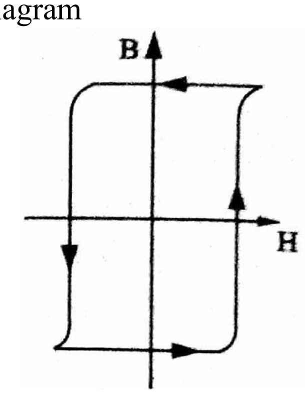
Explanation of Hysteresis based on domain theory

(i) Consider a ferromagnetic material.
(ii) A small magnetic field is applied to the material.
(iii) Hence the domain walls are displaced slightly (*OA*).
(iv) Now the magnetic field is removed.
(v) So the domains return to its original position.
(vi) These domains are called **reversible domains**.
(vii) Now the magnetic field is increased.
(viii) Hence the magnetization increases rapidly with *H*.
(ix) Now the magnetic field is removed.
(x) Hence the domains do not return to its original position. It starts moving (*AB*).
(xi) These domains are called **irreversible domains**.
(xii) Now the magnetic field is further increased.
(xiii) Hence the domains start rotating along the field direction (*BC*).
(xiv) At this position, the material attains maximum magnetization.
(xv) Now the magnetic field is removed. But the material is having maximum magnetization (*OD*).
(xvi) This is called **residual magnetism.**

(xvii) Now the magnetic field is applied in reverse direction to destroy the residual magnetism.

(xviii) It becomes zero at '*E*. This is called **coercivity** (*OE*).

5. Differentiate soft magnetic materials from hard magnetic materials using magnetic phase diagram.

Soft magnetic materials	Hard magnetic materials
1. The materials which can be easily magnetized and demagnetized are called soft magnetic materials.	1. The materials which are very difficult to magnetize and demagnetize are called hard magnetic materials.
2. Movement of domain wall is easy.	2. Movement of domain wall is not easy.
3. Diagram 	3. Diagram 
4. Small magnetic field is enough to produce large magnetization.	4. Large magnetic field is required to produce magnetization.
5. The hysteresis loop is very narrow.	5. The hysteresis loop is very broad.
6. Loop area is less. So hysteresis loss is low.	6. Loop area is large. So hysteresis loss is high.
7. Susceptibility and permeability are high.	7. Susceptibility and permeability are low.
8. Retentivity and coercivity are small.	8. Retentivity and coercivity are large.
9. Eddy current loss is low.	9. Eddy current loss is high.
10. Examples: Iron, Silicon alloys, Ferrites, Garnets etc.	10. Examples: Carbon steel, Tungsten steel, Chromium steel etc.

11. Applications: It is used to make temporary magnets. They are also used in switching devices, electro magnets, matrix storage of computers.	11. Applications: It is used to make permanent magnets. They are also used in magnetic detectors, microphones and magnetic separators.

6. Describe the structure of ferrites. List out its properties and applications.

(or)

What are ferrites? Describe the different types of ferrites structure with suitable diagrams.

Ferrites

Ferrites are the modified structure of iron with no carbon in which the magnetic moments are of unequal magnitudes. They are made by two or more different kinds of atoms.

General formula

$$X^{2+}\ Fe_2^{3+}\ O_4$$

where X^{2+} is a divalent metal ion such as Mg^{2+}, Zn^{2+}, Fe^{2+} etc.

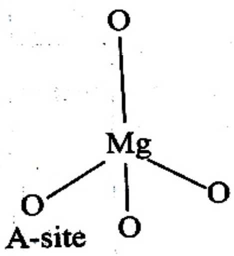
Structure of ferrites

(i) Regular spinal
(ii) Inverse spinal

(i) Regular spinal

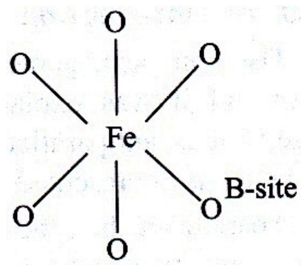
Example: $Mg^{2+}\ Fe_2^{3+}\ O_4$

1. Each Mg^{2+} (divalent) is surrounded by four O^{2-} ions and forms a tetrahedral fashion as shown in the figure. It is called '*A*' site.
2. Totally, there are 8 tetrahedral sites in a unit cell.

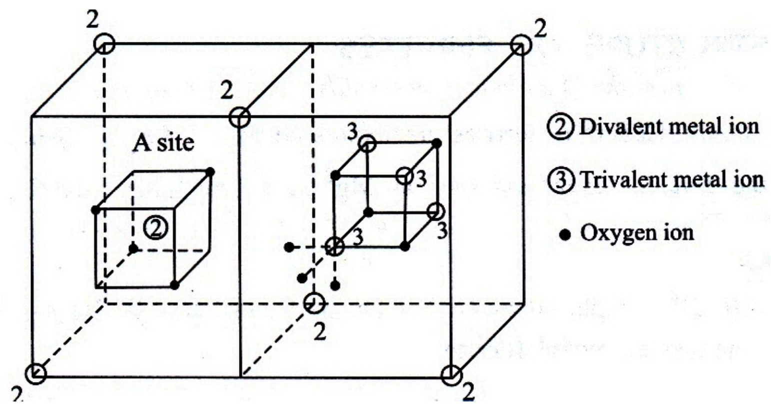


3. Each Fe^{3+} (trivalent) is surrounded by six O^{2-} ions and forms an octahedral fashion as shown in the figure. It is called '*B*' site.

4. Totally, there are 16 octahedral sites in a unit cell.



5. In a regular spinal structure, each divalent metal ion (Mg^{2+}) exists in a tetrahedral form ('*A*' site) and each trivalent metal ion (Fe^{3+}) exists in a octahedral form ('*B*' site).
6. Hence the sites '*A*' and '*B*' combine together to form a regular spinal structure.



(ii) **Inverse spinal**

Example $Fe^{3+}\left[Fe^{2+}\ Fe^{3+}\right]O_4$

1. In this type, the Fe^{3+} ions (trivalent) occupy all the '*A*' sites (tetrahedral) and half of the '*B*' sites (octahedral) also.
2. Thus the left out '*B*' sites will be occupied by the divalent (Fe^{2+}).