UNIT III MAGNETIC PROPERTIES OF MATERIALS 9

Magnetic dipole moment – atomic magnetic moments- magnetic permeability and susceptibility - Magnetic material classification: diamagnetism – paramagnetism – ferromagnetism – antiferromagnetism – ferrimagnetism – Ferromagnetism: origin and exchange interaction- saturation magnetization and Curie temperature – Domain Theory- M versus H behaviour – Hard and soft magnetic materials – examples and uses-– Magnetic principle in computer data storage – Magnetic hard disc (GMR sensor).

UNIT IV OPTICAL PROPERTIES OF MATERIALS 9

Classification of optical materials – carrier generation and recombination processes - Absorption emission and scattering of light in metals, insulators and semiconductors (concepts only) - photo current in a P-N diode – solar cell - LED – Organic LED – Laser diodes – Optical data storage techniques.

UNIT V NANO DEVICES 9

Electron density in bulk material – Size dependence of Fermi energy – Quantum confinement – Quantum structures – Density of states in quantum well, quantum wire and quantum dot structure - Band gap of nanomaterials – Tunneling: single electron phenomena and single electron transistor – Quantum dot laser. Conductivity of metallic nanowires – Ballistic transport – Quantum resistance and conductance – Carbon nanotubes: Properties and applications .

TOTAL : 45 PERIODS

OUTCOMES:

At the end of the course, the students will able to

- ☆ Gain knowledge on classical and quantum electron theories, and energy band structuues,
- ☆ Acquire knowledge on basics of semiconductor physics and its applications in various devices,
- ☆ Get knowledge on magnetic properties of materials and their applications in data storage,
- ☆ Have the necessary understanding on the functioning of optical materials for optoelectronics,
- ☆ Understand the basics of quantum structures and their applications in carbon electronics..

★ ★ ★ ★

UNIT - 3

Magnetic properties of Materials

* Basic defn and
* Magnetic dipole Moment
* Atomic Magnetic Moment
* Bohr magneton
* classification of materials ⟹ Dia, para, ferro
* Curie temperature & Saturation Magnisation
* Domain theory of ferromagnetism.
* Hysteresis - B Vs H curve.
* Antiferromagnetic Materials.
* Ferrimagnetism.
* Soft & hard magnetic materials.
* Applications of Magnetic Materials ⟹
  i) Magnetic Tape
  ii) Magnetic Hard disc
  iii) GMR (giant magneto resistance)

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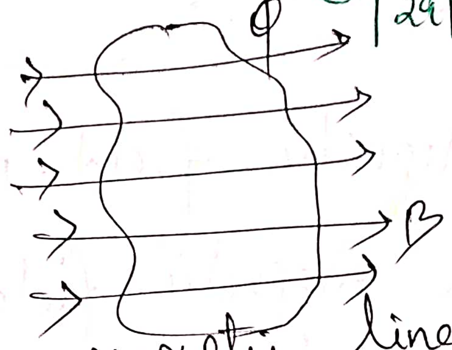
Basic defn:-

1. Magnetic flux (ϕ):



Total number of magnetic lines of force passing through a given area is known as magnetic flux (ϕ). Its unit is weber(wb).

2. Magnetic Induction (B): (flux density)

Total number of magnetic flux passing normally through unit area is known as magnetic Induction. It unit is wb/m^2 (Tesla).

3. Intensity of magnetisation (I)

It is defined as the magnetic Moment per unit volume.

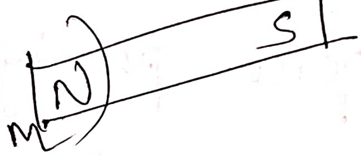
$$\boxed{I = \frac{M}{V}}$$

Its unit : wb/m^3.

4. Magnetic field Intensity | Strength :-

Magnetic field intensity at any point in a magnetic field is the force experienced by a unit north pole placed at that point.

unit : A/m.



5. Magnetic permeability (μ)

It is defined as the ratio b/w the magnetic Induction (B) and the magnetic field Strength (H).

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

In general, $\mu = \mu_0 \cdot \mu_r$

$\mu_r = \mu/\mu_0 \rightarrow$ relative permeability.

* It is the ratio b/w the permeability of the medium to the permeability of free space.

6. Magnetic dipole Moment :-

$$\boxed{M = m \times l}$$

The product of one of the pole strength and Semi length of the bar magnet.

ong ψ
ma χ

7. Magnetic Susceptibility (χ):

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

It is the ratio of intensity of magnetisation (I) induced in it to the applied magnetic field (H).

8. Relation b/w χ & μ_r:

* Magnetic induction in the magnetic material for applied field strength (H) is given by,

$$B = \mu_0 (H + I)$$

$$= \mu_0 H \left(1 + \frac{I}{H}\right)$$

$\left(\chi = \frac{I}{H}\right)$ $B = \mu_0 H (1+\chi)$

$\left(\mu = \frac{B}{H}\right)$ $\frac{B}{H} = \mu_0 (1+\chi)$

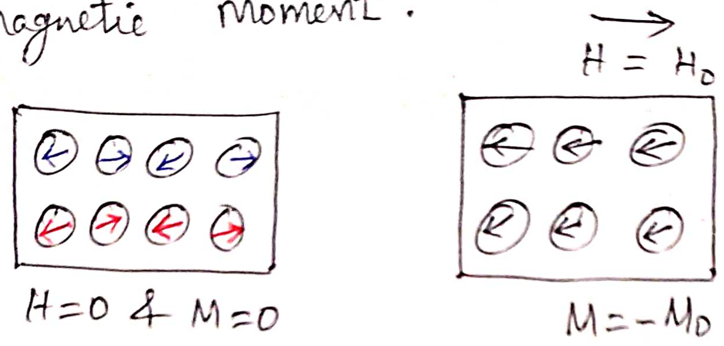
$$\mu = \mu_0 (1+\chi)$$

$$\mu_0 \mu_r = \mu_0 (1+\chi)$$

$\boxed{\mu_r = 1+\chi}$ $\Rightarrow$ $\boxed{\chi = \mu_r - 1}$

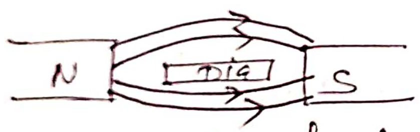
Diamagnetic Materials:-

* Diamagnetism is exhibited by all the materials. The atoms in the diamagnetic materials do not possess permanent magnetic moment.



* When a magnetic field H is zero, the atoms possess zero magnetic moment.

* When a mag. field H_0 is applied in the direction as shown in Fig, the atoms acquire an induced mag. Moment in the direction opposite to that of the field.



* When the material is placed in a magnetic field, the electrons in the atomic orbits tend to counteract the external magnetic field and the atoms acquire an induced magnetic Moment.

Properties:-

1. They repel the magnetic lines of force.
2. There is no permanent dipole moment. therefore the mag. effects are v. small). (weak)

3. The magnetic susceptibility is negative and it is independent of temp and applied mag. field strength.

4. permeability is less than 1.

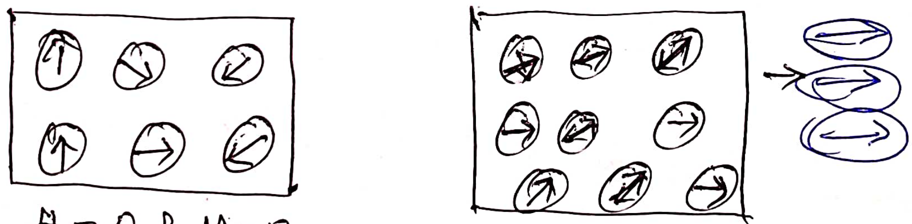
5. when temp is less than critical temperature diamagnetics becomes normal material.

eg: ~~Gold~~, ~~Germanium~~, ~~Silicon~~ etc.,
Pb, Niobium, Tantalum etc,

Paramagnetism:—

* In paramagnetic materials, each atom (or) molecule possess a net permanent magnetic moment even in the absence of an external mag. field.

$H = \vec{H_0}$



$H = 0$ & $M = 0$ $\qquad$ $M = +M_0$

* The mag. Moments are randomly oriented in the absence of an external mag. field. This makes the net magnetic moment zero.

* But when an external mag. field is applied, the mag. dipoles tend to align themselves in the direction of the magnetic field and the material becomes magnetised. This effect is known as Paramagnetism.

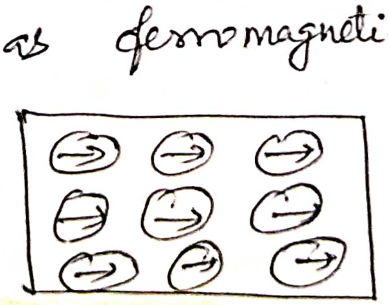
Properties :

1. Paramagnetic materials attract the magnetic lines of forces.
2. They possess permanent dipole moment.
3. The susceptibility is positive and depends on temperature. $\boxed{\chi = \frac{C}{T-\theta}}$ (Curie-Weiss law).
4. permeability is greater than one.
5. When the temp. is less than Curie temperature, Paramagnetic materials becomes diamagnetic materials.

Eg: Nickel Sulphate, $CuSO_4$, $MnSO_4$, Pt etc.,

Ferromagnetism : Certain materials like Fe, Co, Ni, and their alloys exhibit high degree of magnetisation. These materials are called spontaneous magnetization.

Atomic magnetic moments are aligned even in the absence of an external magnetic field. This phenomenon is known as ferromagnetism.



$H = 0$.

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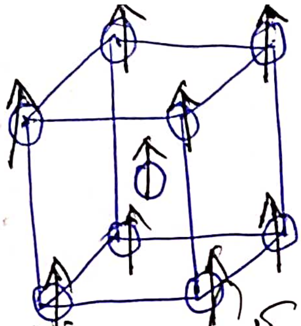
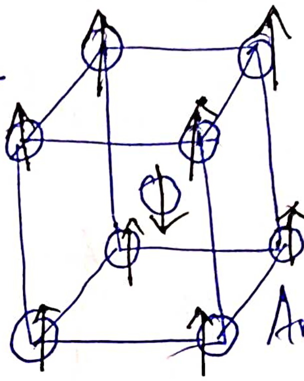
For BCC





Anti ferro.

Properties :- (Ferromagnetic)

1. Some magnetisation is already existing in these materials, all the magnetic lines of force passes through it.

2. They have permanent dipole moment. So they acts as strong magnets.

3. The Susceptibility is positive and high and it is given by $\chi = \frac{C}{T-\theta}$

4. When the temperature is greater than Curie temperature, ferromagnetic material becomes paramag. material.

5. permeability is very much greater than 1.

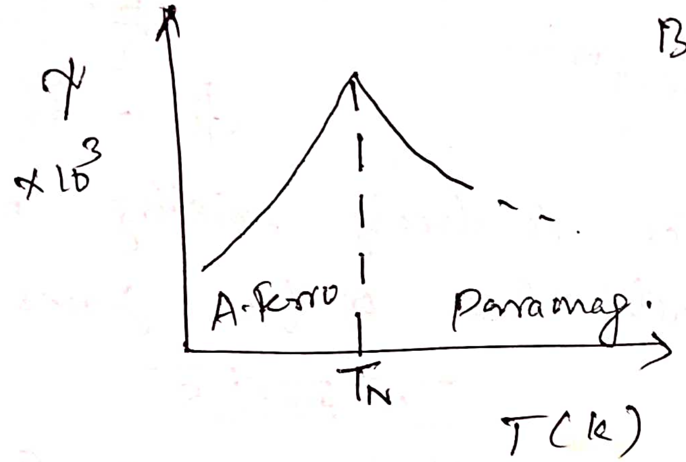
eg :- Ni, Co, Fe etc.,

Antiferromagnetism:

Antiferromagnetic materials are magnetic materials which exhibit a small positive Susceptibility of the order of 10^{-3} to 10^{-5}.

eg: Ionic compounds, MnO, MnS, Cr_2O_3 etc, Neel temperature :

Below TN - Anti ferro magnetic



The Susceptibility increases with increasing temp. and it reaches a maximum at a particular temperature called Neel temperature (T_N).

With further increase in temperature, the material becomes reaches paramagnetic State.

Properties: (Antiferro.)

1. The electron spin of neighbouring atoms are aligned antiparallel. ie, (Spin alignment is antiparallel.)

$\uparrow \downarrow \uparrow \downarrow \uparrow$

2. Antiferromagnetic susceptibility mainly depends on temperature.

3. The Susceptibility of the antiferromagnetic material is small and positive.

$$\boxed{\chi = \frac{C}{T+\theta}} \quad T > T_N$$

Neel temp.

Ferrimagnetism (ferrites)

It is a special case of magnetic materials and it is composed of two sets of different transition metal having different values of mag. moment.

Properties :- 1. The susceptibility is very large and is positive. It represented by, $\chi = \frac{C}{T \pm \theta}$

2. Beyond the Neel temperature, χ decreases.

3. Ferrimagnetic materials possess net magnetic moment.

4. Two or more sets of transition metals are used to prepare the ferrimagnetic materials.

eg: Ferrous ferrite, nickel ferrite etc.,

Structure of Ferrites :- Ferrites are the magnetic compounds consisting of two (or) more different kinds of atoms.

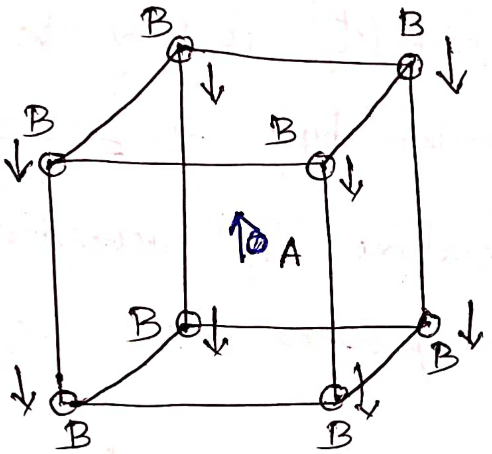
General chemical formula is $X^{2+} Fe_2^{3+} O_4^{2-}$.

Where, X^{2+} is a divalent metal ion such as Fe^{2+}, Mg^{2+}, Ni^{2+}, Co^{2+}, Mn^{2+}.. etc.

Types:
Examples: 1. If x^{2+} is preplaced by Ni^{2+}, then the ferrite ($Ni^{2+} Fe_2^{3+} O_4$) → nickel ferrite.

2. If x^{2+} is replaced by Fe^{2+} then the ferrite ($Fe^{2+} Fe_2^{3+} O_4$) → ferrous ferrite.

~~Magnetic Moment in BCC crystal:-~~



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Application of Ferrites
refer G. Senthil kumar.

Properties of Ferrites :-

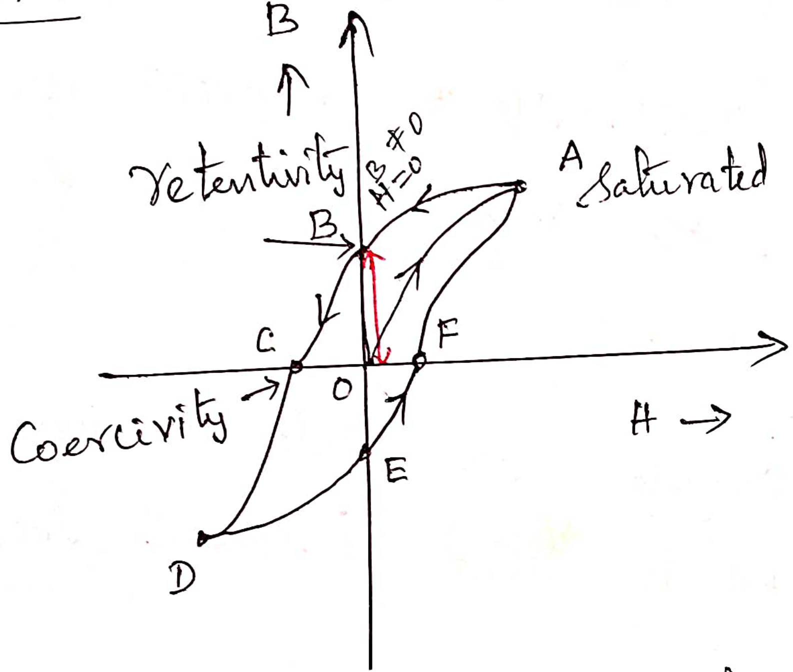
1. Ferrites has net magnetic moment.
2. The susceptibility of ferrite is very large and positive. It is temperature depends, $\chi = \frac{C}{T \pm \theta}$.
3. Spin alignment is antiparallel of different magnitudes as shown in fig. $\uparrow\downarrow\uparrow\downarrow\uparrow$
4. They have high permeability and high resistivity.
5. They have low eddy current losses and low hysteresis losses.

Energy product :- The product of residual magnetic Induction (B) and Coercivity is called E.P.

Hysteresis :-

The word hysteresis means lagging behind.

A graph is drawn by plotting magnetic field Strength (H) along x-axis and mag. induction B along y-axis.



* The magnetic Induction B increases along the curve OA with the magnetic field H, The curve OA is called saturated point (line)

* The value of mag. field is decreased, but the mag. induction does not decrease at the same rate, ~~at which it is increased~~. When $H=0$, $B \neq 0$, line OB is called retentivity (or) residual magnetism.

* The applied magnetic field H is reversed and increased gradually till the point C is reached. The magnetic induction B becomes zero at that point C, and it is known as Coercivity.

* Further increase of mag. field H, the mag. induction increases along CD in the reverse direction as shown in the graph. If the magnetic field is varied backwards, the magnetic induction follows a curve DEFA.

* This will complete one cycle of magnetisation. The loop ABCDEFA is called hysteresis loop.

* The lagging of mag. Induction behind the applied field strength is called magnetic hysteresis.

Hysteresis loss: When a specimen is taken through a cycle of magnetization, then there is a loss of energy in the form of heat. This loss of energy is known as Hysteresis loss.

Difference b/w Soft and Hard magnetic Material.

Soft magnetic material	Hard magnetic material
1. These magnetic materials can be easily magnetised and demagnetised.	These magnetic material can not be easily magnetised and demag.
2. They have high permeability.	They have low permeability.
3. Magnetic energy stored is not high.	Magnetic energy stored is high.
4. Low hysteresis losses due to small hysteresis loop area.	Large hysteresis losses due to large hysteresis loop area.
5. Coercivity and retentivity are small.	Coercivity and rententivity are large.
6. The eddy current loss is small due to its high resistivity.	The eddy current loss is more due to its small resistivity
7. The domain walls are easy to move.	The movement of domain wall must be prevented.
8. eg: Iron silicon alloy, nickel iron alloy, Silicon steel.	eg: Tungsten steel, cobalt steel, etc, கோபால்ட்

9. They are used in electric motor, generators, transformers, relays, telephone receiver, radar and sonar.	They are used in Loud speaker and electrical measuring instruments.

Bohr magneton:-

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

$$1 \text{ Bohr Magneton} \Rightarrow \frac{e\hbar}{2m} = \mu_B$$

$$\mu_B = 9.27 \times 10^{-24} \, Am^2.$$

$$\hbar = \frac{h}{2\pi}$$

$$\mu_B = \frac{eh}{4\pi m} = \frac{1.6 \times 10^{-19} \times 6.6 \times 10^{-34}}{4 \times 3.14 \times 9.1 \times 10^{-31}}$$

$$\mu_B = 9.27 \times 10^{-24} \, Am^2$$

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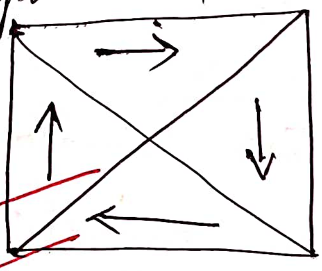
Domain theory of ferromagnetism:

① *. According to weiss, ferromagnetic material consists of a number of small regions called domains.

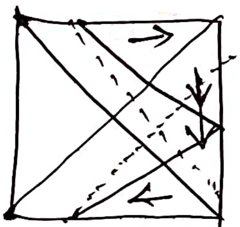
② * The size of a domain varies from 10^{-6} m to entire size of the crystal) ③ A domain acts as a single mag. dipole and has definite boundaries.



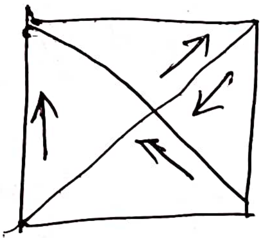
without field

④ These domains have spontaneous magnetisation due to parallel alignment of spin mag. moment in each domain.

But the direction of spontaneous magnetisation varies from domain to domain and are oriented in such a way that the net magnetisation of the specimen is zero.



with field (weak)



with field (strong)

⑤ Now, when the magnetic field is applied, then the magnetisation occurs in the specimen, by two ways.

i) By the moment of domain walls.

ii) By rotation of domains walls.

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i) By the movement of domain walls:

* The movement of domain walls take place in weak magnetic field. Due to this weak field applied to the specimen the magnetic moment increases and hence volume of the domains changes.

ii) By rotation of domains walls:-

The rotation of domain walls takes place in strong magnetic fields. When the external field is high the ~~the~~ magnetisation changes by means of rotation of the direction as shown in Fig.

Types of energy Involved in the Process of domain growth:- there are four types of energy involved in the process of domain growth.

i) Exchange energy.
ii) ~~Magnetostatic energy.~~ Domain wall energy.
iii) Crystal anisotropy energy.
iv) Magnetostriction energy.

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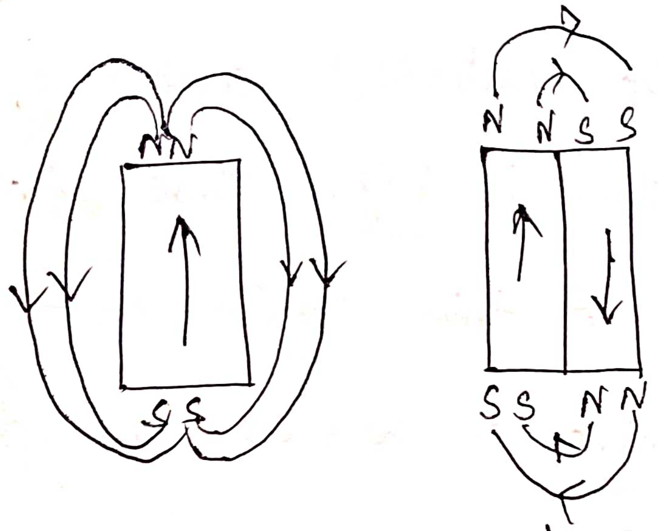
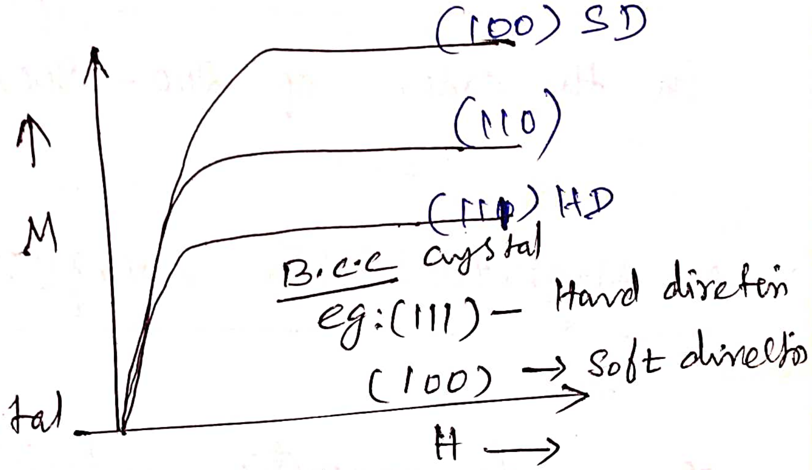


The interaction energy which makes the adjacent dipole to align themselves is known as exchange energy (or) magnetic field energy.

ii) Anisotropy energy:

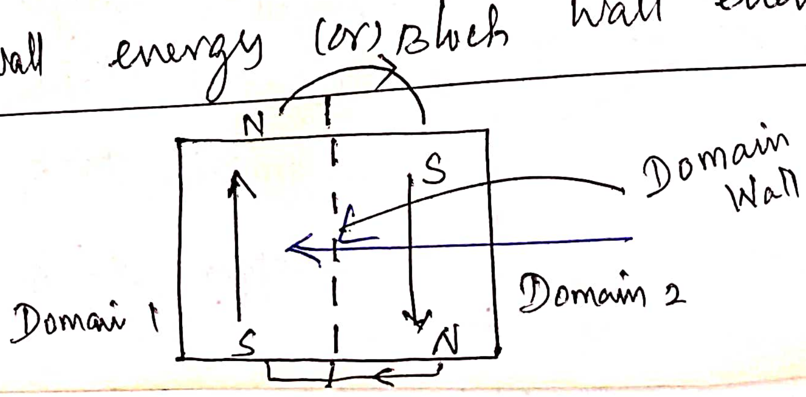


In ferromagnetic crystal there are two direction of magnetisation.

i) Easy direction. ii) Hard direction.

Defn:- The excess of energy required to magnetise the specimen along hard direction over that required to magnetise the specimen along easy direction is called crystalline anisotropy energy.

iii) Domain wall energy (or) Bloch wall energy:-



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Consider the magnetic material consisting of two domain as shown in Fig. These two domain are ⊥r to each other. A thin region that Separates these two domains is known as domain wall or Bloch wall. i.e, Thickness of the walls is in the order of 200 - 300 A°.

A. Magnetostriction energy:

The change in the dimension of a ferromagnetic material, when it is magnetized is known as magnetostriction.

The change in dimension (increase or decrease) depends upon the nature of the material.

eg:- Ni - length decreases (or) Increase is due to the mechanical stress generated by domain rotation.

UNIT-3(a)

Applications of Ferrites:-

i) They are used to produce Ultrasonics by magneto-striction oscillator.

ii) Ferrites (Ni-Zn) are used in audio and video transfomers.

iii) Ferrite rods are used in radio receivers to inerease the Sensitivity.

iv) They are also used for power limiting and harmonic generation.

v) They are used in Computers and data processing circuits.

vi) Ferrites are used in storage devices such as magnetic tapes, floppy discs, hard discs etc.,

Atomic Magnetic Moments:-

i) **Orbital magnetic Moment:-**

The magnetic moment due to the movement of $\bar{e}$ in circular orbit around the nucleus. i.e, orbital magnetic moment.

ii) **Spin Magnetic moment:-**

The magnetic moment due to the spin of electrons in orbits. i.e spin angular momentum.

Expression:- Let us consider an $\bar{e}$ moving with a constant speed "v" in a circular orbit of radius r.

The Current, $I = \frac{\text{charge of } \bar{e}}{\text{Time}}$

$$I = \frac{-e}{T} \longrightarrow ①$$

$(A = \pi r^2)$

Magnetic moment,

$$\mu_L = \text{Current} \times \text{Area}$$

$$\boxed{\mu_L = I A}$$

$$\mu_L = \frac{-e}{T} \times \pi r^2 \longrightarrow ②$$

Velocity, $v = \frac{2\pi r}{T}$

$$T = \frac{2\pi r}{v}$$ sub in eqn. 1

$$= \frac{\cancel{2\pi r}}{\cancel{2\pi r / T}}$$

$$I = \frac{-e}{\frac{2\pi r}{v}} = \frac{-e.v}{2\pi r}$$ sub in eqn. 2.

$$\mu_L = \frac{-ev}{2\cancel{\pi}\cancel{r}} \times \cancel{\pi} r^{\cancel{2}} = \frac{-evr}{2} \rightarrow (3).$$

$$\mu_L = \frac{-evr \times m}{2m}$$ charge

$$L = mvr$$

$$\boxed{\mu_L = -\frac{eL}{2m}} \longrightarrow (4)$$

The expression is known as magnetic moment associated with the orbital motion of $\bar{e}$.

2m

Saturation Magnetization:-

Defn:- The maximum magnetisation in a ferromagnet when all the atomic magnetic moments are aligned is called saturation magnetization.

(2M) Curie temperature:- (T_c)

The ferromagnetic behaviour disappears at a critical temperature called the Curie temperature.

(May 2015)

1. A magnetic field strength of 2×10^5 A/m is applied to a paramagnetic material with a relative permeability of 1.01. Calculate the value of B & I.

Data:

$H = 2 \times 10^5$ A/m

$\mu_r = 1.01$.

Solution

$\chi = \mu_r - 1$

$\frac{I}{H} = \mu_r - 1$

$I = H(\mu_r - 1)$

$= 2 \times 10^5 (1.01 - 1)$

$I = 2 \times 0.01 \times 10^5 = 2 \times 10^3$ Wb/m^2.

Also

$B = \mu_0 (H + I)$

$= 4\pi \times 10^{-7} (2 \times 10^5 + 2 \times 10^3)$

$= 4 \times 3.14 \times 10^{-7} \times (0.02 + 2) \times 10^5$

$B = 4 \times 3.14 \times 2.02 \times 10^{-2}$

$$\boxed{B = 0.253 \text{ Tesla}}$$

(Dec-2014)

2. The magnetic field intensity of a paramagnetic material is 10^4 A/m. At room temperature its susceptibility is 3.7×10^{-3}. Calculate the magnetization of the material.

Data

$I = ?$, $H = 10^4$ A/m.

$\chi = 3.7 \times 10^{-3}$.

Solution :-

$\chi = I/H$

$I = \chi . H$

$= 3.7 \times 10^{-3} \times 10^4$

$= 3.7 \times 10$

$$\boxed{I = 37 \text{ wb/m}^2}$$