Chapter-4. Magnetic Materials

Magnetic permeability and susceptibility:

(i) Permeability

Magnetic permeability of the medium at any point is defined as the magnetic field per unit magnetizing field.

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

μ represents to what extent a medium is permeable by a magnetic field.

(ii) Relative Permeability

Relative permeability of the medium is defined as fractional increase in the field with respect to the field in free space when a material medium is introduced.

$$\mu_r = \frac{B}{B_0} = \frac{B}{\mu_0 H}$$

$$\mu_r = \frac{\mu}{\mu_0} \left[B/H = \mu \right]$$

$$\boxed{\therefore \mu = \mu_0 \mu_r}$$

(iii) Susceptibility :-

Magnetic susceptibility is a dimensionless proportionality constant that indicates the degree of magnetization of a material in response to an applied magnetic field.

$$\chi = M/H \quad \therefore \quad M = \chi H$$

If M denotes magnetic ~~field~~ dipole moment per unit volume, H denotes magnetic field strength then magnetic induction B is given by,

$$B = B_0 + \mu_0 M$$
$$B = \mu_0 (H + \chi_m H)$$
$$B = \mu_0 (\chi_m + 1) H$$
$$B = \mu_0 \mu_r H$$

where, $\mu_r = \chi_m + 1$

Types of ~~Ferro~~magnetism:-

(i) Ferromagnetism:

→ These materials gets easily/strongly magnetized after the application of magnetic field.

→ Ferromagnetic materials can possess large permanent magnetization even in the absence of an applied field.

→ Magnetic Susceptibility (χ_m) is positive & very large and depends on the applied field intensity.

→ The relationship between magnetization M and $\mu_0 H$ is highly non-linear.

→ Ferromagnetism occurs below a critical temp^r (T_c) called curie temperature and above this temp^r ferromagnetism is lost.

It follows Curie-Weiss Law,

$$\chi = \frac{C}{T - T_c}$$

C = Constant for the material

T = absolute temp^r

T_c = Curie temp^r

eg. Iron, nickel, cobalt.

② Ferrimagnetism :- eg. XFe_3O_4 where X = Mg, Cu, Mn, Ni, Zn, Cd, etc.

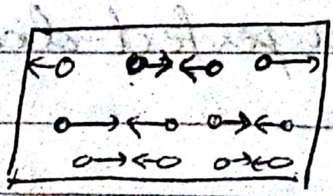
→ It is mainly seen in ferrites, (oxide iron ore) (magnetite) → Fe_3O_4

→ It is similar to that of ferromagnetism; difference being on two factors.

(i) Curie temp^r :- Curie temp^r is low for ferrimagnetic materials.

(ii) Alignment of magnetic Domains:

(Read book to get clarified.)



magnetic moments of the allignments are different.

Magnetic ordering in ferrimagnetic materials.

→ Ferrimagnetic materials ~~have~~ are non-conducting so, they do not suffer from eddy current losses. That is why, they are used for high frequency electronic application.

③ Paramagnetism :-

→ Paramagnetic materials have small positive magnetic susceptibility. ($\times 10^{-2}$ range)

→ In the absence of external magnetic field, atomic moments (magnetic moments) are randomly oriented due to random collision of molecules. So, the avg. dipole moment and the net magnetization are both zero.

$(B = \mu_0 H)$

→ But when an external field is applied they get feebly magnetized and is equal to $\chi_m H$.

since, $\boxed{\chi_m = \frac{M}{H}}$ $\Rightarrow M = \chi_m H$

→ degree of magnetisation increases with increasing field (i.e increase in $\mu_0 H$) & vice-versa. degree of magnetisation decrease with increase in temperature

→ It follows curie law given by,

$$\boxed{\chi_m = \frac{C}{T}}$$

eg. Pt, Al, Cr, Mn, etc.

④ Diamagnetism

→ These materials have negative magnetic susceptibility., a perfect diamagnet with $\chi_m = -1$.

→ When diamagnetic materials are placed in magnetic field, the magnetization vector (M) is in opposite direction to the applied field. This causes the magnetic field within the material to be less than the applied field.

→ The negative susceptibility can be interpreted as the diamagnetic substance trying to expel the applied field from within the material.

→ Covalent crystals & many ionic crystals are diamagnetic.

eg. Bi, Sb, Au, Cu, Hg, etc.

⑤ Anti-ferromagnetism

→ have small positive susceptibility

→ In the absence of external field, there is no net magnetization of the material.

→ They possess magnetic ordering in which the magnetic moments on alternating atoms in the crystals align in opposite directions.

→ Antiferromagnetism exists below a critical tempr called Neel tempr.

→ Above this they are paramagnetic.

eg. MnO, FeO, CoO, NiO, $FeCl_3$, $KMnO_4$; Cr, Mn

Domain Structure :-

When cooled below a temp^r called curie temp^r, the magnetization of a ferro-magnetic material spontaneously divides into many small regions called magnetic domain.

A magnetic domain is the region within a magnetic material in which the magnetization is in uniform direction. This means that individual magnetic moments of the atoms are aligned with one another and they point in the same ~~structure~~ direction. The magnetization within each points is a uniform direction but the magnetization of different different domains may point in different directions. Domain Structure is responsible for ferromagnetism.

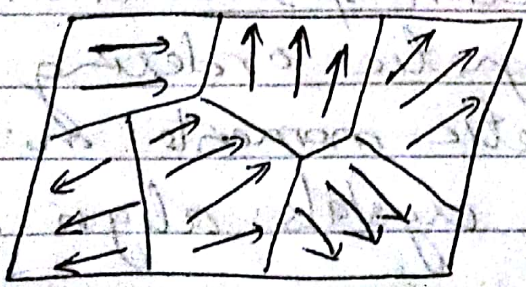
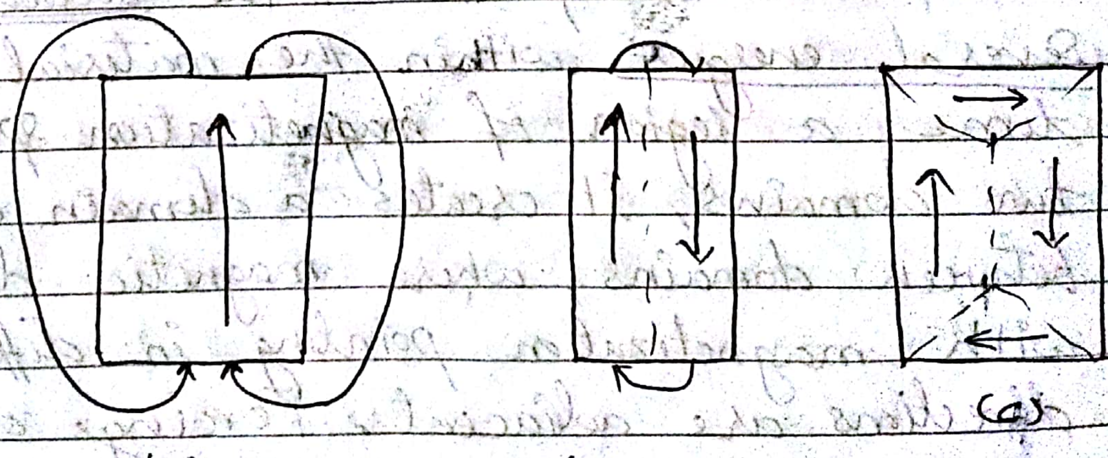


Fig: Domains in unmagnetized iron.

Why domains form :-

The reason a piece of magnetic material such as iron spontaneously divides into separate domains rather than exist in a state with magnetization in the same direction throughout the material, is to minimize internal energy.

A large region of ferromagnetic materials with a constant magnetization throughout will create a large magnetic field extending into the space outside itself. This requires a lot of energy stored in the field.



(a) (b) (c)

Fig : How dividing a ferromagnetic materials domains reduces the magnetostatic energy.

To reduce magnetostatic energy, sample can split into two domains, with the magnetization in opposite directions in each domain. To reduce the field energy further, each of these domains can split also resulting in smaller parallel domains with magnetization in altering directions, with smaller amounts of field outside the material.

Size of domain and domain walls :-

A domain which is too big is unstable, and will divide into smaller domains. The size of domain depends on the balance of several energies within the material. Each time a region of magnetization splits into two domains, it creates a domain wall between domains, where magnetic dipoles with magnetization pointing in different directions are adjacent. Forcing adjacent dipoles to point in different directions require energy. The domains keep dividing into smaller domains until the energy cost of creating an additional domain wall is just equal to field energy saved.

Then the domains of this size are stable.

(ii) Size of domain walls

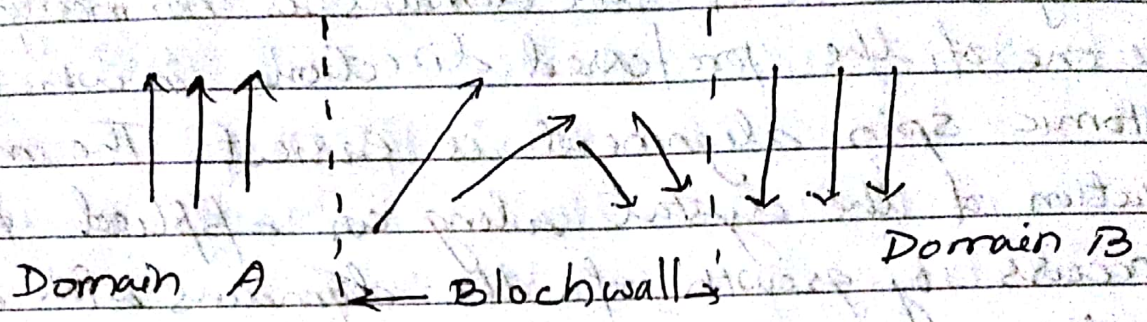


Fig: Domain & Domain walls.

Exchange forces between neighbouring atomic spins favour very little relative motion. Domain wall has neighbouring atomic spins rotated gradually and over several hundred atomic spacing the magnetic moments reach a rotation of 180°. If the exchange forces only were responsible, relative rotation would be so little that the wall would have to be so thick. However magnetic moments that are oriented away from easy directions posses excess energy called anisotropy energy which tries to decrease wall thickness. wall thickness is a compromise between exchange energy requiring thick wall and anisotropy energy requiring thin wall.

Magnetization of ferromagnetic materials with external field

Magnetization of the domains is normally along the one of the preferred directions in which the atomic spin alignment is easiest. The magnetization of the crystal along an applied field occurs by growth of the domains with magnetization ~~of the crystal~~ along the applied field.

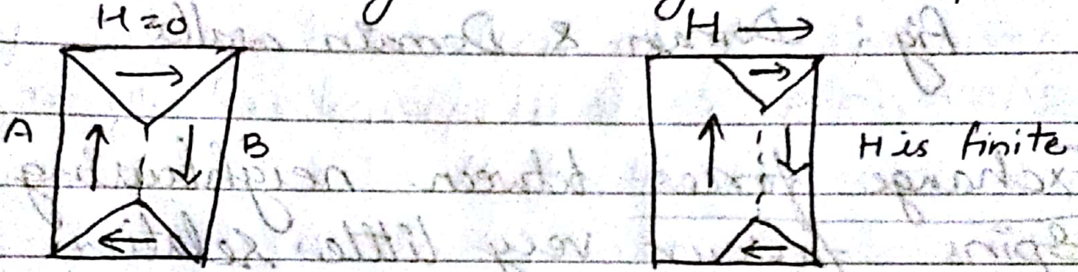


Fig : Domain structure in absence and presence of field.

The bloch wall between domains A and B migrates towards right enlarging domain A and shrinking domain B. The migration of Bloch wall is caused by the spins in the wall & also spins in the region B adjacent to the wall ~~and~~ also being gradually rotated by the field. The magnetization process involves the motion of Bloch walls in the crystal

B-H curve and Hysteresis loop.

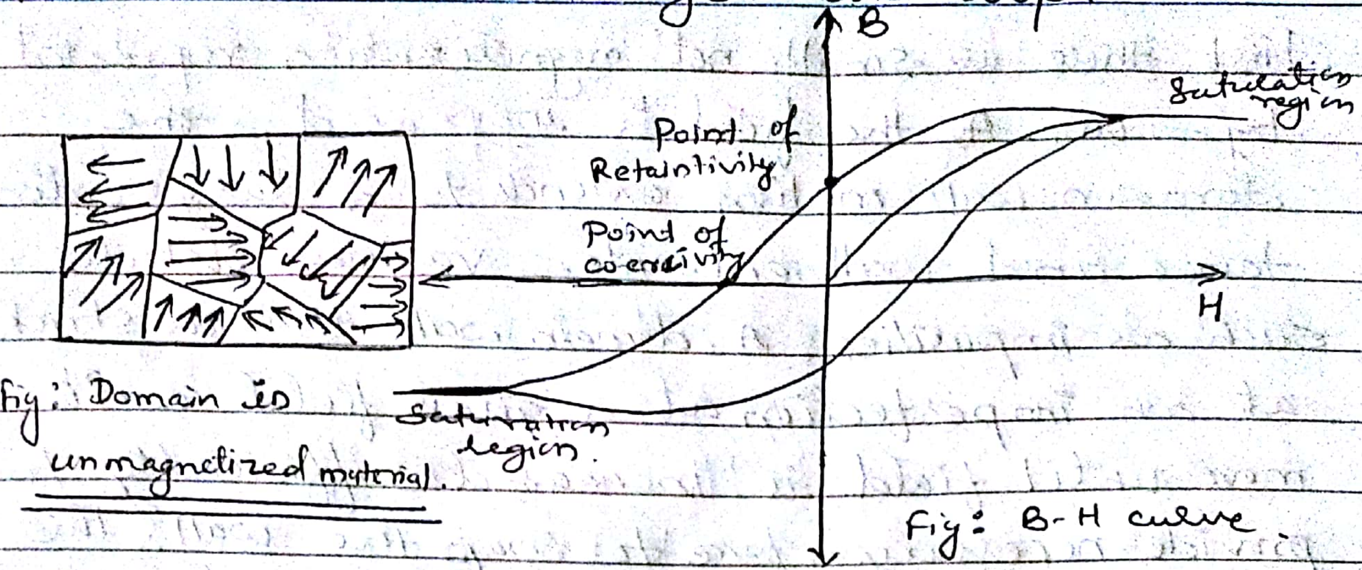


Fig: Domain in unmagnetized material.

Fig: B-H curve.

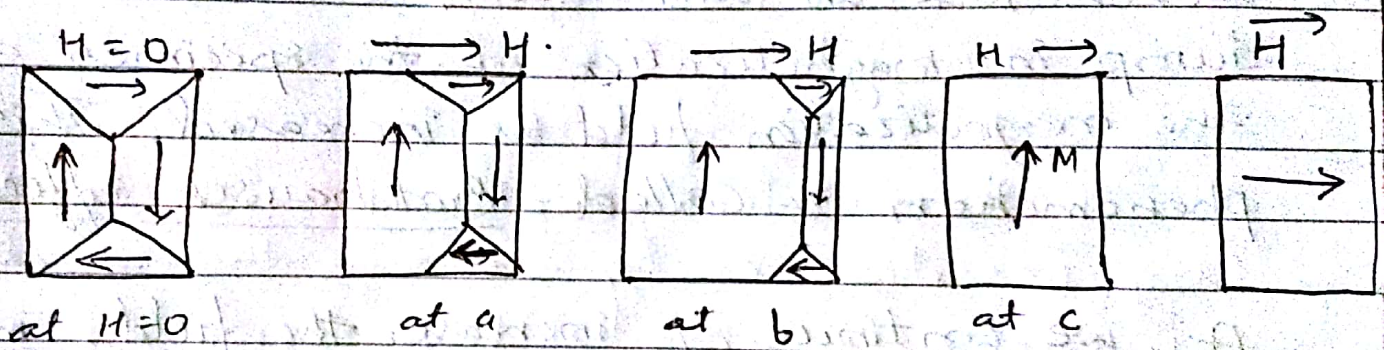


Fig: Behaviour of polycrystalline in external magnetic field.

In unmagnetized polycrystalline sample, each crystal grain possess domain which depends on shape and size of the grain and magnetization of neighbouring grain. When a small field is applied in x-direction, then the domain wall move by small distance and net magnetization is seen on +ve x-direction.

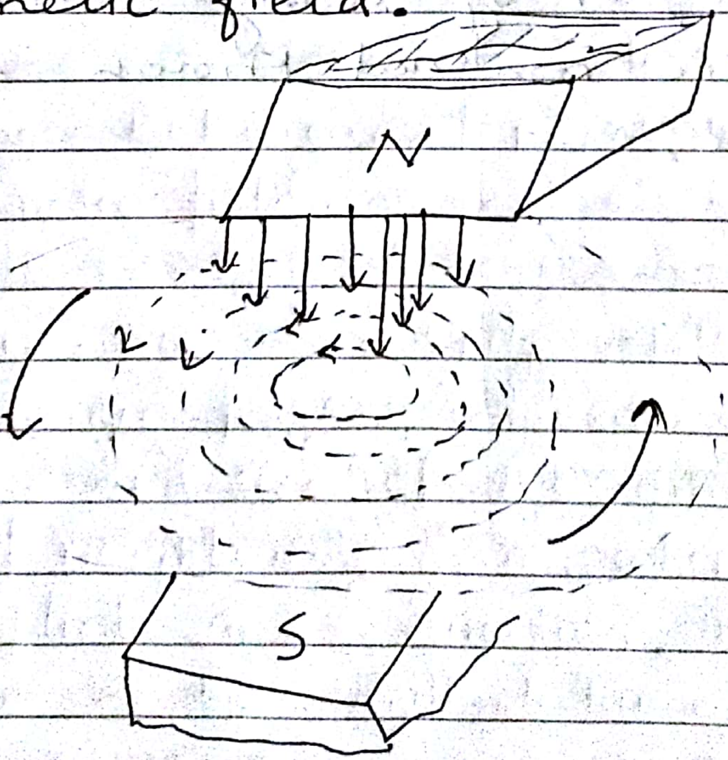
First there is small net magnetization represted by oa. As the field is increased, the domain wall motion extends to a larger distance and wall encounters various obstacles such as impurities. A domain wall that is stuck at an imperfection at a given field can't move until field is increased sufficiently to provide necessary force to snap the wall. This sudden jerk in wall motion leads to small jump in magnetization of the specimen as the magnetization field is increased. This phenomenon is called Barkhausen effect.

As we continue to increase the field, magnetization increases by jerk domain wall motion and get saturated. If we decrease and remove the magnetization, each grain will rotate to align parallel with the nearest easy direction. There is certain magnetization left after removal of magnetic field called residual magnetization (M_r). If new field is applied in reverse direction magnetization will decrease and becomes zero for certain field (H_c).

Further increase in field in opposite direction cause the effect same as above but in opposite direction.

Eddy current Loss :->

Eddy currents are loops of electric currents induced within conductors by a changing magnetic field in the conductor, due to Faraday's laws of induction. Eddy Current flow in closed loops within conductors, in planes perpendicular to the magnetic field.



By Lenz Law, an eddy current creates a magnetic field that opposes the magnetic field that created it.

Eddy currents generate resistive losses that transform some forms of energy, such as kinetic energy into heat. This Joule heating reduces efficiency of iron-core transformers and electric motors and other devices that use changing magnetic fields. Eddy currents are minimized in these devices by selecting magnetic core materials that have low electrical conductivity (eg. Ferrites) or by using thin sheets of magnetic material known as Laminations.

Hard and Soft Magnetic Materials

	Hard Magnetic Materials	Soft Magnetic materials
1)	Materials which retain their magnetism and are difficult to magnetize are called hard magnetic materials. These materials retain their magnetism even after removal of the applied magnetic field. Hence these materials are used for making Permanent magnets. In permanent magnets, the movement of domain wall is prevented. They are prepared by heating the magnetic materials to the required temp^r & then quenching them. Impurities increases the strength of hard magnetic material.	Soft magnetic materials are easy to magnetize and demagnetize. These materials are used for making temporary magnets. The domain wall movement is easy. Hence, they are easy to magnetize. By annealing the cold worked materials, the dislocation density is reduced and domain wall movement is made easier. Soft magnetic materials should not possess any void and its structure should be homogenous so that the materials are not affected by impurities.

2) They have large hysteresis loos due to large hysteresis loop area.	2) They have low hysteresis loss due to small hysteresis area,
3) Susceptibility and peermeability are low.	3) Susceptibility and permeability are high.
4) Coercitivity and retentivity are large.	4) Coercivity and ~~tente~~ rentenitivity values are less.
5) Magnetic energy stored is high.	5) Since they have low retentivity and coescivity they are not used for making permanent magnets.
6) They posses high value of BH product.	6) — low
7) Eddy current loss is high.	7) Eddy current loss is less.
eg: iron, cobalt & aluminium,	eg: iron-silicon alloys, Nickel-iron alloy

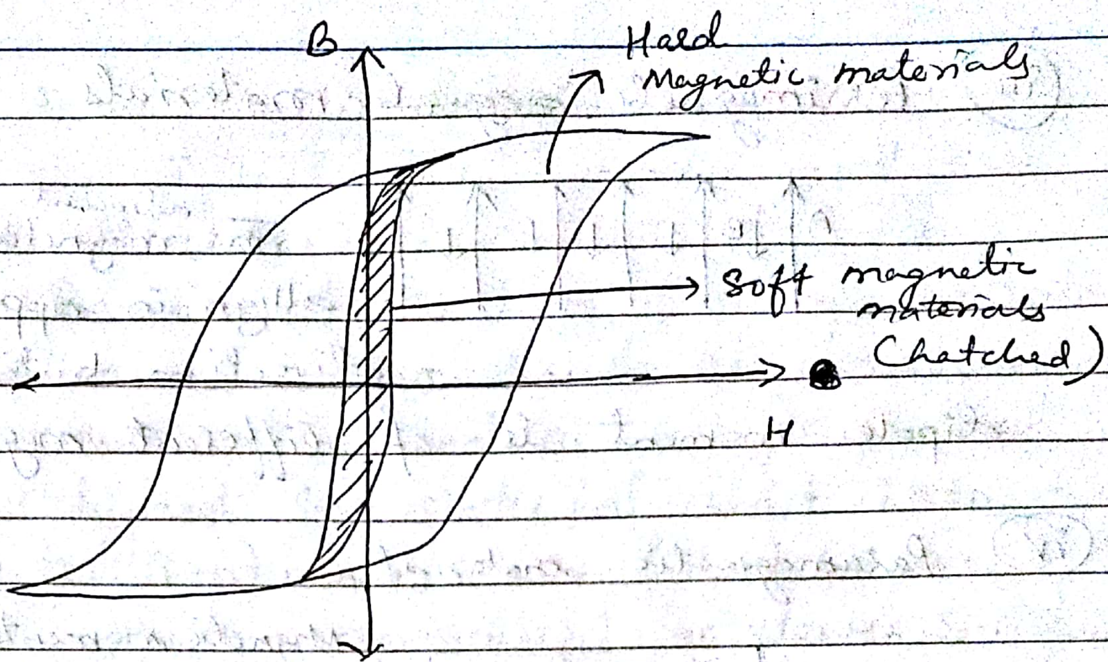
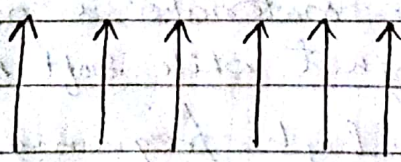


Fig: B-H Curve for Hard & Soft Magnetic material.

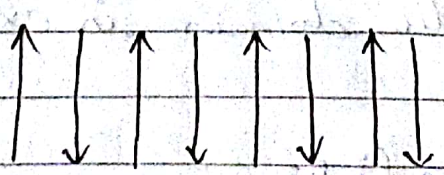
Alignment of magnetic moment in different materials.

(i) Ferromagnetic Material.



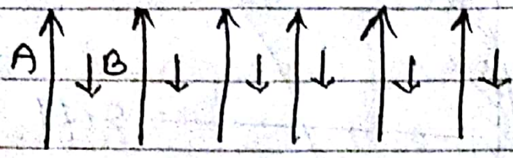
magnetic moments are alligned in same direction.

(ii) Antiferromagnetic material.



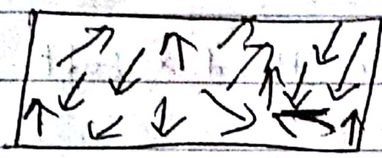
adjacent magnetic moments are alligned in opposite direction but have same dipole moment.

(iii) Ferrimagnetic ~~magnetic~~ materials



The adjacent magnetic moments allign in opposite direction but the dipole moment is of different magnitude.

(iv) Paramagnetic material



Magnetic moments are randomly alligned, but net magnetization in a material is zero.

Questions

① Classify magnetic materials & explain them briefly.
② Why hard magnetic materials is preferred for making permanent magnet while soft magnetic material is used for high frequency application.
③ Explain significance of hysteresis loop
④ What are magnetic domains? Explain the behaviour of magnetic domain in external magnetic field?

⑤ Explain domain theory of magnetism?

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