Magnetization factor. (B) H

$B = \mu_0 H$

Chapter-5 Chapter:Five

Magnetic materials & superconductivity

Effective factors of Magnetic materials

Many electrical engineering devices such as inductors, transformers, rotating machines etc are based on the utilization of magnetic properties of materials. To understand magnetic materials and magnetism properly we need to know following quantities first.

1. Magnetic Dipole moment
2. Atomic magnetic moment
3. Magnetization vector 'M'

For magnetization vector 'M'.

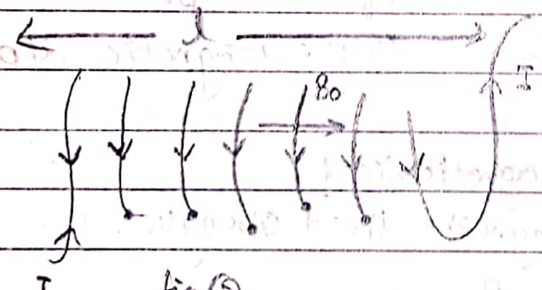


fig (a)

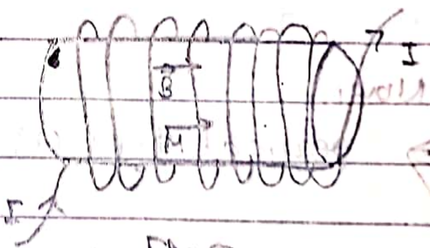


Fig (b)

For (a)

Consider a long solenoid with the free space as the medium inside the magnetic field B0.

→ A material medium inserted into the solenoid develops a magnetisation M.

$$\boxed{M = \frac{1}{\Delta V} \sum_{i=1}^{N} \mu_{m_i} = n_{at} \mu_{av}}$$

no of atom

Each atom of the material response to the applied field B_0 and develops a net magnetic moment μ_m along the applied field. The medium therefore develops a net magnetic moment along the field and becomes magnetized. M is defined as the magnetic dipole moment per unit volume. suppose that there are N atoms in a small volume ΔV and each atoms, i has a magnetic moment μ_{mi} (where $i = 1, 2, \ldots, n$) then we can write the magnetization vector

$$M = \frac{1}{\Delta V} \sum_{i=1}^{N} \mu_{mi} = n_{at} \mu_{av}$$

where,

n_{at} = no. of atoms per unit volume.

μ_{av} = average magnetic dipole moment.

Now,

$\Rightarrow$ permeability (μ) = $\frac{\text{magnetic field}}{\text{magnetic field strength}}$

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

$\Rightarrow$ Relative permeability (μ_r) $= \frac{B}{B_0} = \frac{\mu H}{\mu_0 H} = \frac{\mu}{\mu_0}$

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

$$\Rightarrow \mu = \mu_0 \mu_r$$

Suppose that at a point in a material, the magnetic field and magnetization field (magnetic field ~~or magnetic flux~~ ~~etens~~ strength) is, H. Let B_0 be the magnetic field at the same point in the absence of any material (i.e in the free space). The magnetic permeability of the medium at p is defined as the magnetic field per unit magnetizing field i.e,

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

Magnetizing field is measured in A/m.

Relative permeability (μ_r)

μ_r of the medium is the fractional increased in the magnetic field with respect to the field in free space when the material medium is introduced. For eg: suppose that the field in a solenoid with free space in it is B_0 but with material inserted is B then μ_r is defined by,

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

where, μ_0 = absolute permeability

The magnetisation M, produced in a material depends on the net magnetic field B.

Now, the magnetic ~~susbe~~ succeptiblity (χ_m) of the medium is defined simply by,

$$\boxed{M = \chi_m H}$$

And also we have the relation,

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

or, $\frac{B}{\mu_0 H} = 1 + \chi_m$

or, $\frac{B}{B_0} = 1 + \chi_m$

$$\therefore \boxed{\mu_r = 1 + \chi_m}$$

which gives the relationship between the relative permeability and succeptibility.

⊗ $B = \cancel{\mu_0 H} \ \mu n I$

Q.1 A magnetic material has the magnetization of 3300 A/m and flux density of 0.0044 wb/m² (Tesla). Calculate the magnetic field strength and relative permeability of the material.

Soln

Given,

magnetization (M) = 330 A/m

flux density (B) = 0.0044 wb/m^2

$H = ?$

$\mu_r = ?$

Now,

we know that,

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

or, $0.0044 = 4\pi \times 10^{-7} (H + 330)$

$\therefore H = \cancel{3171.40}\ 200$

Then,

$$M = \chi_m H$$

or, $\chi_m = \frac{M}{H} = \frac{330}{200}$

$$\chi_m = 16.5$$

Again,

$$\mu_r = 1 + \chi_m$$
$$= 1 + 16.5$$
$$= 17.5$$

Q. 2. The magnetic field strength in a piece of copper is 10^6 A/m. Given that the magnetic susceptibility of copper is -0.5. Find the magnetic flux density and the magnetization in copper. Also find out the relative permeability of the copper.

Soln,

$$H = 10^6 \text{ A/m}$$
$$\chi_m = -0.5$$
$$B_0 = ?$$
$$\mu_r = ?$$
$$M = ?$$

Now,

$$\mu_r = 1 + \chi_m = 1 - 0.5$$
$$= 0.5$$

Then,

$$M = H \chi_m$$
$$= 10^6 * (-0.5)$$
$$= -5 \times 10^5$$

And,

$$\cancel{\mu_r =} \; B_0 = \mu_0 (H + M)$$
$$= 4\pi \times 10^{-7} \left(10^6 + (-5 \times 10^5)\right)$$
$$= 0.628 \text{ T}$$

Q. 3. Find the percentage increase in the magnetic field B, when the space within a current carrying ~~the~~ coil is filled with aluminium. Given that, the susceptibility of aluminium is 2.1×10^{-5}.

Soln

Given,

Susceptibility of aluminium (χ_m) = 2.1×10^{-5}

Initially magnetic field (B_0) $= \mu_0 H$ — (i)

After filled with aluminium (B) $= \mu_0 (H + M)$ — (ii)

$= \mu_0 (1 + \chi_m) H$ — (ii)

Then,

change in magnetic field $= B - B_0$

$= \mu_0 (1 + \chi_m) H - \mu_0 H$

$= \mu_0 H (1 + \chi_m - 1)$

$= \mu_0 H \cdot \chi_m$

Now,

percentage change in magnetic field $= \frac{B - B_0}{B_0} \times 100\%$

$= \frac{\mu_0 H \chi_m}{\mu_0 H} * 100\%$

$= \chi_m * 100\%$

$= 2.1 \times 10^{-5} * 100\%$

$= 2.1 \times 10^{-3}\%$

Above curie temp, material shows dia & paramagnetic materials.

Magnetic materials classification

1. Diamagnetic materials
2. Para magnetic materials
3. Ferro magnetic materials.
4. Anti feromagnetic materials
5. Ferrimagnetic materials.

Eg!) → water, air (magnetic behaviour dekhna difficult)

Basic type (Small +ve value of χ_m, ~~net magnetic moment 0~~ → shows magnetic behaviour)

1. Diamagnetic material

Materials with negative succeptibility are termed as diamagnetic substances. Their relative permeability is slightly less than unity. when diamagnetic materials are placed in a magnetic field, the magnetisation vector m is in opposite direction to the applied field. These causes the magnetic field within the material to be less than the applied field. The negative succeptibility can be interpreted as the diamagnetic substance trying to expel the applied field within the material. Co-valent crystals and many ionic crystals are diamagnetic because the constituent atoms has no unfilled sub-shell. Super conductors are perfect diamagnetic with $\chi_m = -1$ and totally expels the applied field. some examples are Cu, Bi, H_2O, air and some organic materials.

2. Para magnetic material

Para magnetic materials have small positive magnetic succeptibility. In the absence of external magnetic field, molecular moments (or atomic moments) are randomly oriented due to the random collison of molecules. So the average dipole moment and the net magnetization both are zero. When an external field is applied, μ_{av} becomes non-zero and depends upon the applied field $\mu_0 H$ and hence the magnetization is also non-zero and equal to $\chi_m H$. Magnetization M, increases with $\mu_0 H$ but decreases with increase in temperature in paramagnetic material.

Many gases and metals are paramagnetic nature. The typical value of magnetic succeptibility, $\chi_m = 1.2 \times 10^{-5}$ for metals and 2.1×10^{-6} for oxygen. Other examples are Al, Cr, Mn, etc

8. Ferromagnetic materials

Ferromagnetic materials can posses large ~~mag~~ permanent magnetisation even in the absence of an applied field. The magnetic succeptibility, K_m is positive and very large and depends upon the applied field intensity. The relationship between magnetization, M and $\mu_0 H$ is highly non-linear.

The ferromagnetic crystals has magnetic moments of all crystal aligned in an orderly manner so as to give rise to the net-magnetisation, M. Ferromagnetism occurs below a critical temperature, T_c is caued Curie temperature. At the temperature above this, ferromagnetism is lost and the substance becomes para-magnetic or diamagnetic. For eg: Fe, Ni, Co

Ferro ko opposite

4. Anti ferromagnetism

Anti ferro magnetic materials have small positive susceptibility. In the absence of external field, there is no net magnetisation of the material. They posses magnetic order, in which the magnetic moments on alternating atoms in the crystals aligned in opposite directions. Anti ferromagnetism occurs below a critical temperature called Neel temperature. Above these temperature, they becomes paramagnetic. Anti ferro magnetic substances are feably magnetised when subjected to a strong magnetic field.
eg: MnO, FeO, NiO etc.

5. Ferrimagnetic material

Ferri magnetic materials exhibit magnetic behaviour similar to ferromagnetism below a critical temperature called curie temperature.

As ~~seen~~ shown in the figure aside, all A - atoms has their spins aligned in one direction and all B - atoms has their spins aligned in opposite direction of A.

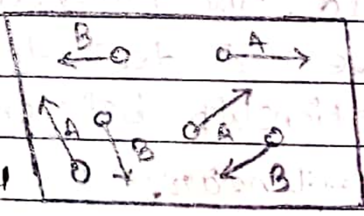


fig: Magnetic ordering in ferrimagnetic crystal.

Magnetic moment of A is greater than that of ~~atoms~~. Due to this reason, there will be net magnetisation, M in the crystal even in the absence of external applied field. These materials are non conducting. Examples are, XFe_3O_4 where, X = Cu, Mg, Mn, Ni, Zn etc.

V. V. Imp

Domain theory of ferromagnetism.

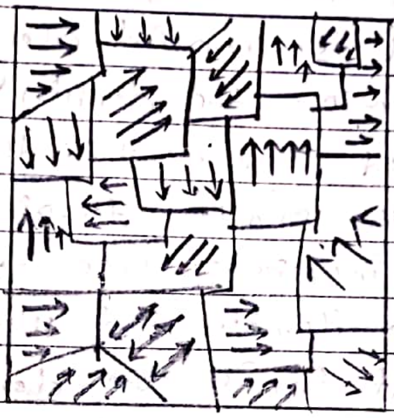


fig. Domain structure of ferromagnetic materials

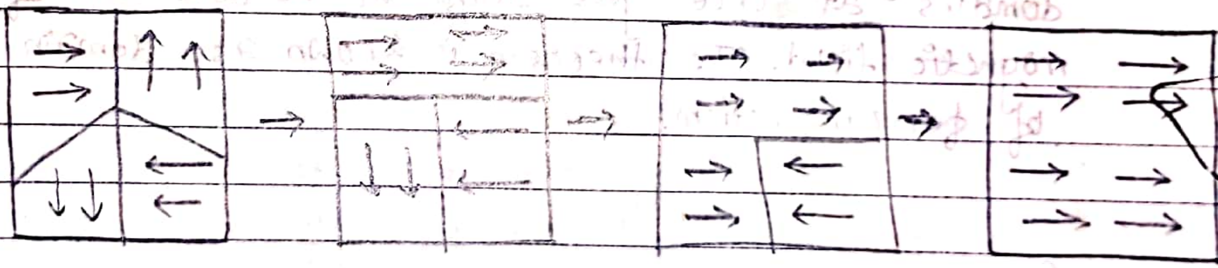


fig. showing the behaviour of magnet with increasing magnetic field.

Ferromagnetic materials or substances contain a large number of small regions known as domain. The direction of magnetic moment of all the atoms ~~of~~ in the domain remains same. but its direction may or may not be same as in neighbouring domain. The magnetic moments in the different domains are oriented in such a way that the net magnetic moment

tends to zero resistance
or, tends to infinite conductivity } it behaves as super conductor
it is theoritical assumptions
no doping factor, no impurities.

of a substance is zero. i.e the effect of magnetic moment in a domain is cancelled by that in another domain. Thus, a magnetic substance will not be kept as a magnet. when a magnetic field is applied along a magnetic substance along it's direction, the domain in which the direction of magnetic field is parallel to the applied magnetic field expands over the another domain. If the magnetic field is gradually increases, these domain goes on same direction over the another domain and ultimately the direction of magnetic moment in all the domain gets align in the direction of applied magnetic field. Thus, the specimen gets magnetized. If strong magnetic field is applied along the magnetic substance, the magnetic moments in different domains at once gets align in the direction of applied magnetic field. The theorem is known as domain theory of ferromagnetism.

Super conductivity

Certain metals and alloy exhibits almost zero resistivity i.e infinite conductivity when ~~pulled~~ cooled to sufficiently low temperature. This phenomenon is called super conductivity. In 1911 AD, kame-leigh onnes found that the resistance of mercury dropped down to zero below 4.2k (-269°c). i.e its resistivity ~~rer~~ totally vanishes, and material behaves as a super conductor exhibiting no resistance to the current flow. Since then 100's of such types of substances have been discovered which exhibit super conductivity when cooled below a critical temperature that depends upon a material.

1 Oc

* Meissner effect

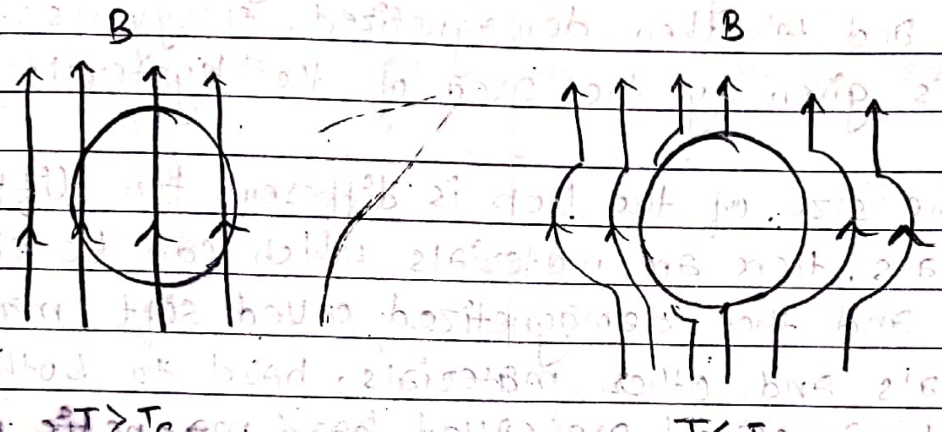


Fig: super conducting sphere above Tc.

fig: super conducting sphere below Tc

If a magnetic field is applied to a material in the super conducting state then it is found that the superconductor expells the magnetic field and acts as an ideal diamagnetic substance provided that the magnetic field is weak. This phenomena of repulsion of magnetic field from the surface of the super conductor is called Meissener effect.

* Hystersis loop

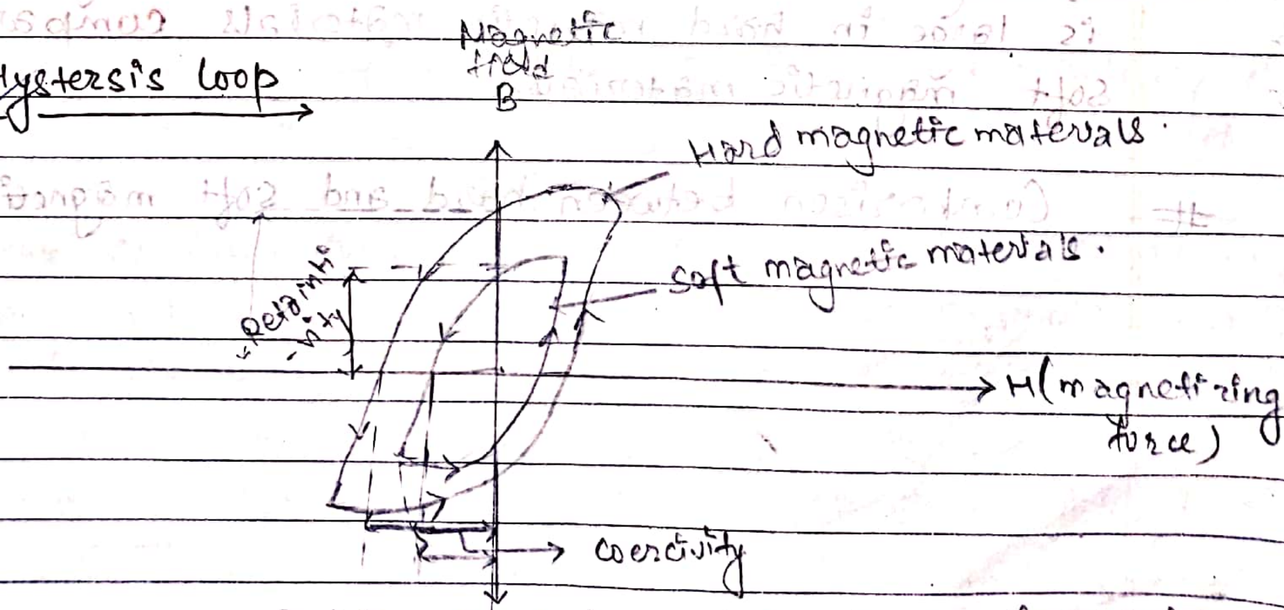


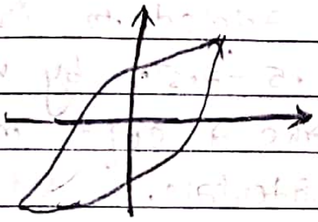
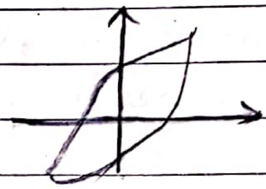
Fig: B-H Curve for hard & soft magnetic material

When a magnetic material is magnetised in a certain limit and ~~wt~~ then demagnetized, energy loss takes place that is given by the area of the Hysteresis loop.

The size of the loop is different for different materials, there are materials which can be easily magne-tized and then demagnetized called soft magnetic materials and other materials, hard to both magnetized and demagnetized are called hard magnetic materials. So according to the B-H behaviour, magnetic materials are classified into soft magnetic materials and hard magnetic materials.

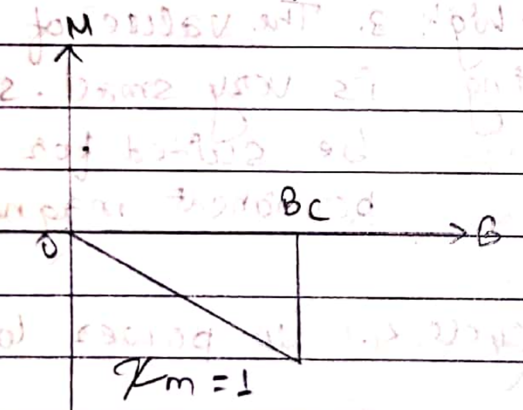
The value of retaintivity (which is the value of magnetic field in a zero-magnetic field intensity) is large enough in hard magnetic materials than the soft magnetic materials). The value of coercivity (which is the value of magnetic field intensity in a zero-magnetic field) is large in hard magnetic materials compares to soft magnetic materials).

Comparison between hard and soft magnetic material

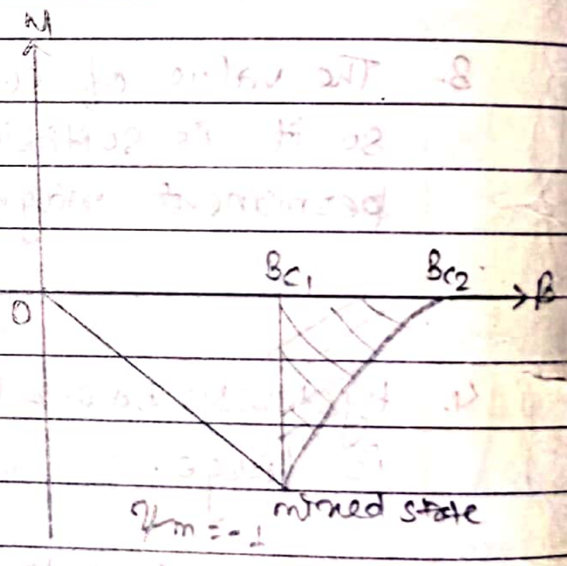
Hard magnetic materials	Soft magnetic materials
1. Hysteresis loss area is large. 	1. Smaller hysteresis loss area. 
2. Cannot be easily magnetized and demagnetized.	2. Can be easily magnetized and de-magnetized.
3. The value of coercivity is high so it is suitable for making permanent magnet.	3. The value of coercivity is very small, so it cannot be suited for making permanent magnet.
4. Hysteresis power loss for cycle is large.	4. No power loss.
5. It requires large magnetic field intensity.	5. It requires relatively low magnetic field intensity.
6. Alloys of aluminium, nickel, and steel, and iron are the best examples.	6. Silicon steel is the most suitable example of soft magnetic materials and generally used for making transformer ~~core~~ core.

7. Al, Ni, Co are high quality permanent magnets used in various electric measuring instruments.	7. Fe-Si alloys; which is the composition of iron and silicon in which silicon is added to iron about 0.5-2.5% by weight to make a soft magnetic materials.

Type-I and Type-II super conductors



fig(i): Type-I super conductor



fig(ii): Type-II super conductor

Superconductors are classified into two types; Type-I and Type-II based on their diamagnetic properties. In type-I superconductor, as the applied magnetic field, B increases, the opposing magnetization, M increases until the field reaches the critical value (B_c) where the value of properties of superconductivity disappears. At that point, the perfect diamagnetic behaviour, the Meissner ~~Messiner~~ effect is lost as shown in the above fig (a). The type-I superconductor below B_c, is in the Meissner ~~ef~~ state where it rejects all the magnetic field lines from the interior of the samples. Above B_c, it is in the normal state where the magnetic field lines penetrate the ~~center~~ sample.

In the case of type-II superconductors, the transition doesnot occur sharply from the meissner state to the normal state. But goes through certain extra region of the samples. As the magnetic field is increased initially the sample behaves as the perfect ~~diama~~ diamagnet exhibiting the meissner effect rejecting all the magnetic field lines.

When the applied field increases above a critical field denoted as B_{c_1}, the lower critical field; the magnetic field lines are no longer totally expels from the sample. The over-all magnetization, M in the sample opposes the field. As the field increases, M gets smaller and more flux lines penetrate through the sample until B_{c_2}, upper critical field and in this situation the superconductivity disappears.

Therefore, type-II superconductors has two phases of field B_{c_1} and B_{c_2}. The state between B_{c_1} and B_{c_2} is called the mixed state. All the engineering applications of

temp ↑ or ↓ garda dielectric ko value ↑ or ↓
vayara conducting huna lagyo ra
tyo time ko dielectric loss.

→ limiting value ⇒ dielectric strength (it losses its property at certain time)

superconductors in variably used type-II materials because typically B_{c_2} is much ~~grea~~ better than B_c found in type-I materials and furthermore the critical temperature of type-II superconductors are higher than those of type-I.

... diyara electricity generate garne

Domain Structure and Domain wall.

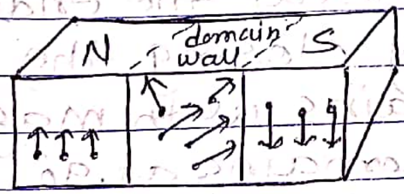


fig: Reversal of magnetism across domain wall.

The internal field in a ferromagnetic material tend to produce localized region of magnetic dipoles is called domains. The boundary between two domains is called domain wall or Block wall.

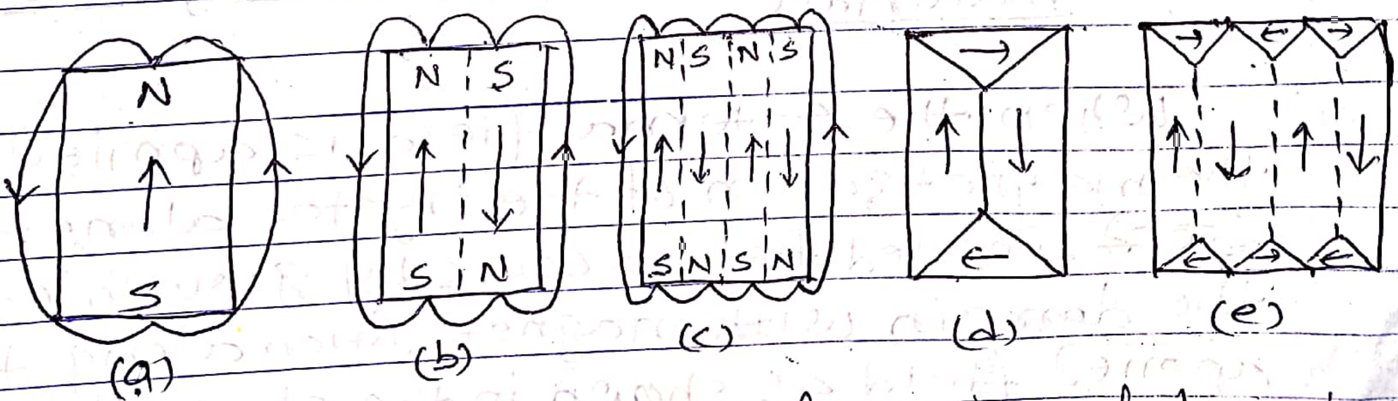
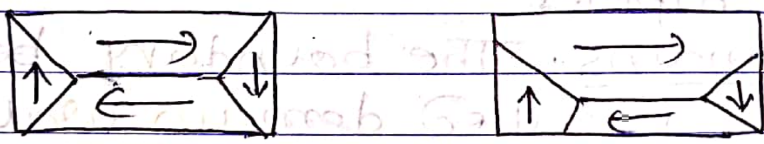


fig.(2) Energy reduction by formation of domains

In above figure 2(a), we have a single domain. In fig 2(b), the magnetic energy is reduced by roughly one half by dividing the crystal into two domains magnetized in opposite direction. In 2(c) with N domains (say) the magnetic energy is reduced to approximately $1/N$ of magnetic energy of 2(a), because of the reduced spatial extension of the field. The magnetostatic energy associated with the field lines at the ends can be further reduced by closing the ends with sideway domains with magnetization 90°. These sideway domains at 90° with the main domains core are called end domains as shown in figure 2(d) and figure 2(e). Here, the magnetic energy is zero.



Randomly oriented domains, $H=0$.

Domain growth with field applied.

fig (3) Domain growth in a ferromagnetic materials.

When the external field is applied the magnetization of the crystal along ~~field~~ applied field occurs by growth o the domain with magnetization along applied field as shown in the above fig.

(*) Losses in Magnetic materials:

When magnetic materials are subjected to changing magnetic field (flux), two types of losses occur which are
(1) Eddy current loss.
(2) Hysteresis loss.

(1.) Eddy current loss:

When applied magnetic field is changed, current is induced in magnetic materials. This current is called eddy current. This eddy current produces loss in power resulting in heating of materials called eddy current loss. To reduce this loss, resistance is made large. Very high resistance of material allow only very small current and consequently very small eddy current loss.

(2.) Hysteresis loss:-

→ Discussed already.

//.