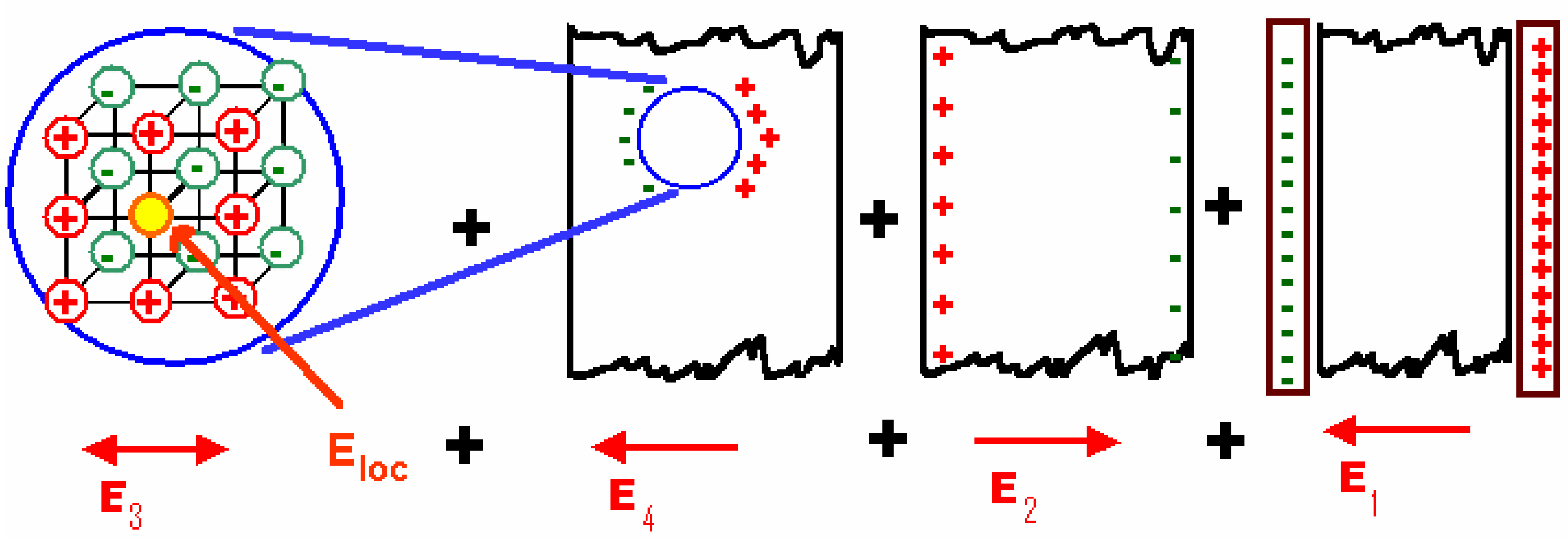
Internal Fields in Solids: (Lorentz Method)

Let a dielectric be placed between the plates of a parallel plate capacitor and let there be an imaginary spherical cavity around the atom *A* inside the dielectric. It is also assumed that the radius of the cavity is large compared to the radius of the atom.



The internal field at the atom site *A* can be considered to be made up of the following four components namely *E1*, *E2*, *E3*, and *E4*.

Field *E1*

E1 is the filed intensity at *A* due to the charge density on the plates. From the field theory

$$E_1 = D / \varepsilon_0$$

$$D = P + \varepsilon_0 E$$

$$\therefore E_1 = \frac{P + \varepsilon_0 E}{\varepsilon_0} = E + \frac{P}{\varepsilon_0} \longrightarrow \quad (1)$$

Field ***E2***

E2 is the field intensity at *A* due to the charge density induced on the two sides of the dielectric.

$$\text{Therefore } E_2 = -\frac{P}{\varepsilon_0} \longrightarrow \quad (2)$$

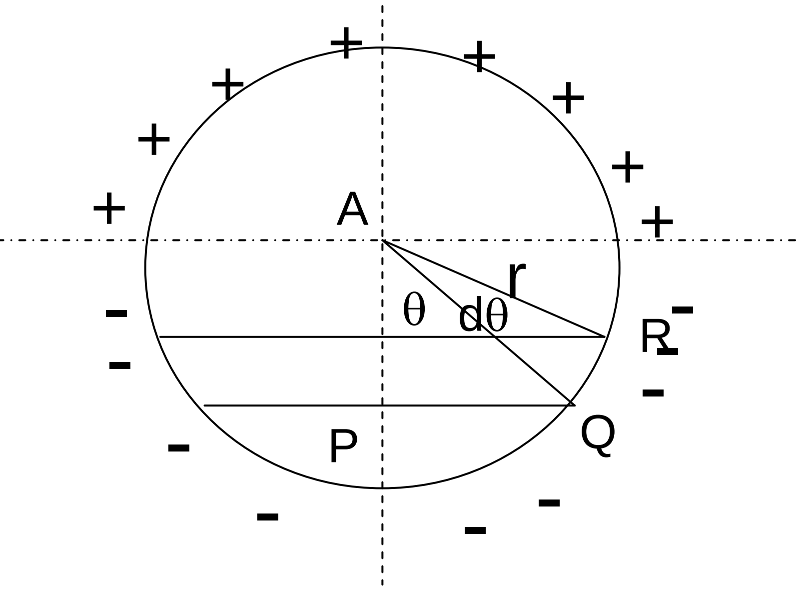
Field *E3*

E_3 is the field intensity at *A* due to other atoms contained in the cavity. We are assuming a cubic structure, so E_3 = 0 because of symmetry.

$$E_3 = 0 \longrightarrow \quad (3)$$

Field E_4

E_4 is the field intensity due to polarization charges on the surface of the cavity and was calculated by Lorentz as given below.



θ is the polar angle to the polarization direction, The surface charge density on the surface of the cavity is –P Cos θ.

If dA is the area of the thin section, charge on the surface element is

$$dq = -P \cos\theta \, dA \longrightarrow \quad (4)$$

If test charge q placed at centre, the Couloumb's law

$$dF = \frac{1}{4\pi\varepsilon_0}\frac{qP\cos\theta dA}{r^2};$$

$$dE_3 = \frac{dF}{q} = \frac{1}{4\pi\varepsilon_0}\frac{P\cos\theta dA}{r^2} \longrightarrow \quad (5)$$

If dA is the surface area of the sphere of radius r lying between θ and $\theta + d\theta$ is the direction with reference to the direction of the applied force,

$$\text{then } dA = 2\pi(PQ)(QR)$$

$$\text{but } \sin\theta = PQ/r, \quad PQ = r\sin\theta$$

$$\text{and } d\theta = QR/r, \; QR = r\,d\theta$$

$$\text{Hence } dA = 2\pi\, r\sin\theta\, r d\theta = 2\pi\, r^2 \sin\theta\, d\theta \quad \rightarrow (6)$$

The charge dq on the surface dA is equal to the normal component of the polarization multiplied by the surface area.

$$\text{Therefore } dq = -P\cos\theta\, dA = P(2\pi r^2 \sin\theta\cos\theta\, d\theta) \quad \rightarrow (7)$$

The field due to this charge at A, denoted by dE_4 in the direction $\theta = 0$

$$dE_4 = \frac{dq \cos\theta}{4\pi\varepsilon_0 r^2}$$

$$= \frac{-p\cos\theta}{4\pi\varepsilon_0 r^2}\frac{2\pi r^2 \sin\theta d\theta \cos\theta}{}$$

$$= \frac{-P}{2\varepsilon_0}\cos^2\theta \sin\theta d\theta \qquad \longrightarrow \qquad (8)$$

Thus the total field E_4 due to the charges on the surface of the entire cavity is obtained by integrating

$$\int dE_4 = \frac{-P}{2\varepsilon_0}\int_0^{\pi}\cos^2\theta \sin\theta d\theta$$

Cos θ = z ; Then dz = - sin θ dθ

$$= \frac{P}{2\varepsilon_0}\int_1^{-1} z^2 dz$$

$$= \frac{P}{2\varepsilon_0}\left[\frac{z^3}{3}\right]_1^{-1}$$

$$= \frac{P}{3\varepsilon_0} \qquad \longrightarrow \qquad (9)$$

The total internal field may be expressed as

Eq.(1) + (2) + (3) + (9)

$$\mathbf{E}_i = \mathbf{E}_1 + \mathbf{E}_2 + \mathbf{E}_3 + \mathbf{E}_4$$

$$E_i = E + \frac{P}{3\varepsilon_0} \longrightarrow \quad (10)$$

Eqn. (10); E_i is the *internal field* or also called *Lorentz field.*

Clausius – Mosotti relation

Let us consider the elemental dielectric material, in which there are no ions and permanent dipoles. The ionic polarizability al and Orientational polarizability α_0 are zero.

$$\alpha_i = \alpha_0 = 0 \longrightarrow (1)$$

Hence polarization $P = N \alpha_e E_i \longrightarrow (2)$

From the internal field E_i

$$= N\alpha_e\left(E + \frac{P}{3\varepsilon_0}\right)$$

$$\text{i.e., } P\left\{1 - \frac{N\alpha_e}{3\varepsilon_0}\right\} = N\alpha_e E$$

$$P = \frac{N\alpha_e E}{\left(1 - \frac{N\alpha_e}{3\varepsilon_0}\right)} \longrightarrow (3)$$

$$D = P + \varepsilon_0 E$$

$$P = D - \varepsilon_0 E$$

$$\frac{P}{E} = \frac{D}{E} - \varepsilon_0 = \varepsilon - \varepsilon_0 = \varepsilon_0 \varepsilon_r - \varepsilon_0$$

$$P = E\varepsilon_0(\varepsilon_r - 1) \longrightarrow (4)$$

$$P = E\varepsilon_0(\varepsilon_r - 1) = \frac{N\alpha_e E}{1 - \frac{N\alpha_e}{3\varepsilon_0}}$$

$$1 - \frac{N\alpha_e}{3\varepsilon_o} = \frac{N\alpha_e}{\varepsilon_0(\varepsilon_r - 1)}$$

$$1 = \frac{N\alpha_e}{3\varepsilon_0}\left(1 + \frac{3}{\varepsilon_r - 1}\right)$$

i.e., $$\frac{N\alpha_e}{3\varepsilon_0} = \frac{1}{1 + \left(\frac{3}{\varepsilon_r - 1}\right)} = \frac{\varepsilon_r - 1}{\varepsilon_r + 2}$$

Thus $$\left(\frac{\varepsilon_r - 1}{\varepsilon_r + 2}\right) = \frac{N\alpha_e}{3\varepsilon_0} \longrightarrow (5)$$

The equation (5) is known as Clausius – Mosotti equation. Where N is the number of molecules per unit volume, one can determine the value of polarizability knowing the value of relative permittivity.

The eqn (5) may be expressed in the following form.
Multiplying M/ρ

$$\frac{M}{\rho}\frac{N\alpha}{3\varepsilon_0} = \alpha_m = \frac{M}{\rho}\frac{\varepsilon_r - 1}{\varepsilon_r + 1} = \frac{N_A\alpha}{3\varepsilon_0}$$

α_m – molar polarizability

M – Molecular weight

ρ - density

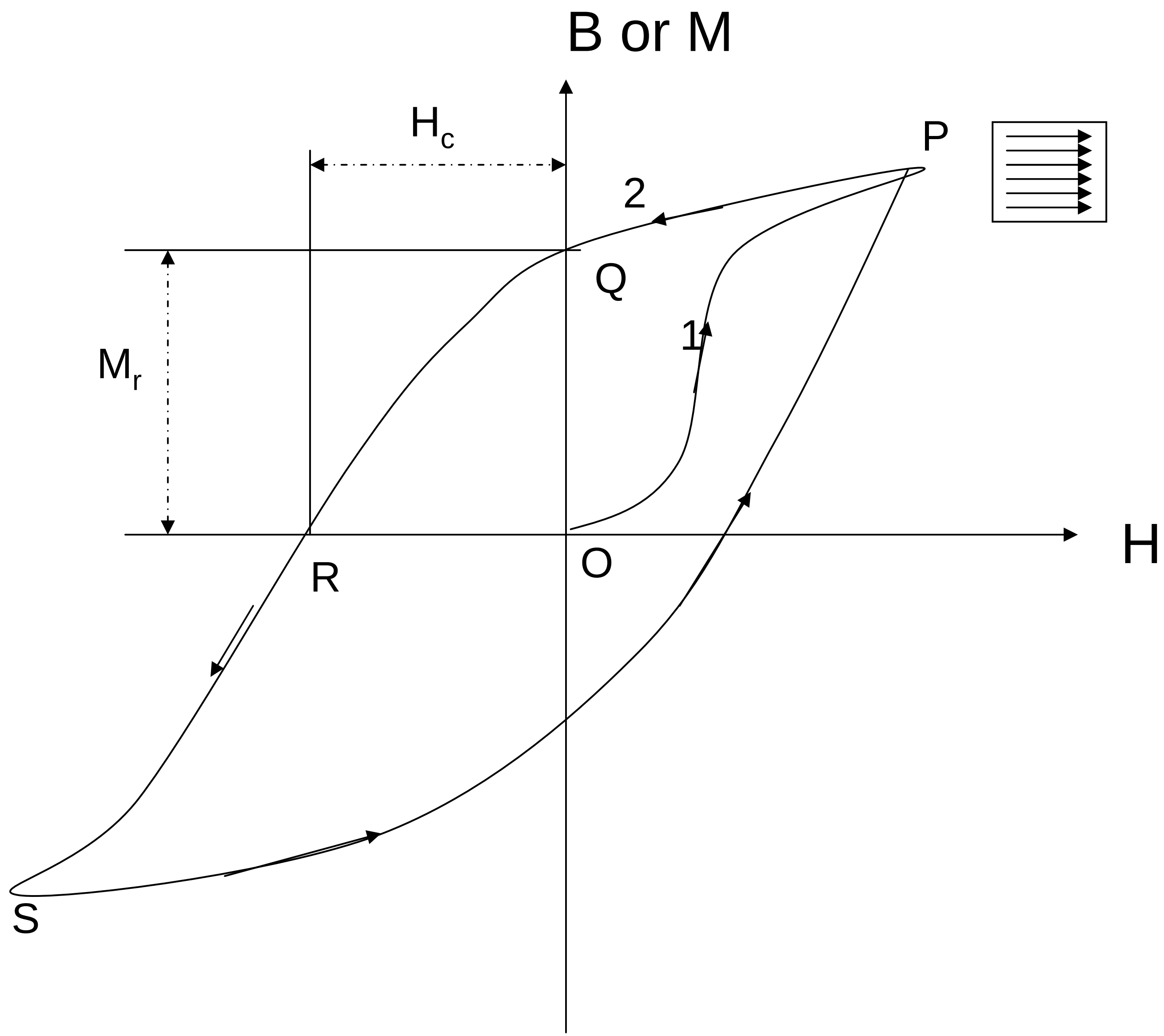
N_a – Avagadro number

HYSTERESIS:

A striking property of the ferromagnetic materials is the relation between magnetization and the strength of the magnetizing field. This property is called *hysteresis*.

The literal meaning of the word hysteresis is the “retardation or lagging of an effect behind the cause is the magnetizing field ‘H’ and the effect that is being produced in the ferromagnetic material.

A plot of M Vs H gives an interesting curve are also drawn relating magnetic induction ‘B’ and the magnetizing field H because B can be measured directly.



Hysterisis curve M or B Vs. H

Significant features of the hysteresis curve are:

(i) If we start with a demagnetized specimen, $M = 0$, with the increasing values of the magnetizing field H, the magnetization of the specimen increases from zero to higher values. The increase is non-linear. By the time P is reached the maximum magnetization is attained. Beyond this point even if H is increased M remains unchanged.

This value of $M = M_S$ is termed as saturation of magnetization. At this state all the molecular dipoles get aligned along the H direction. Hence, the magnitude of M stops increasing any further.

Next coming to the curve 2 of the loop, M does not decrease in phase with the decreasing H. The lagging of M behind H is significant as H attains zero value. We notice that enough amount of $M = M_r$ is left behind instead of tending to zero along with H at $H = 0$. This value of M which persists at $H=0$ is called the residual magnetization.

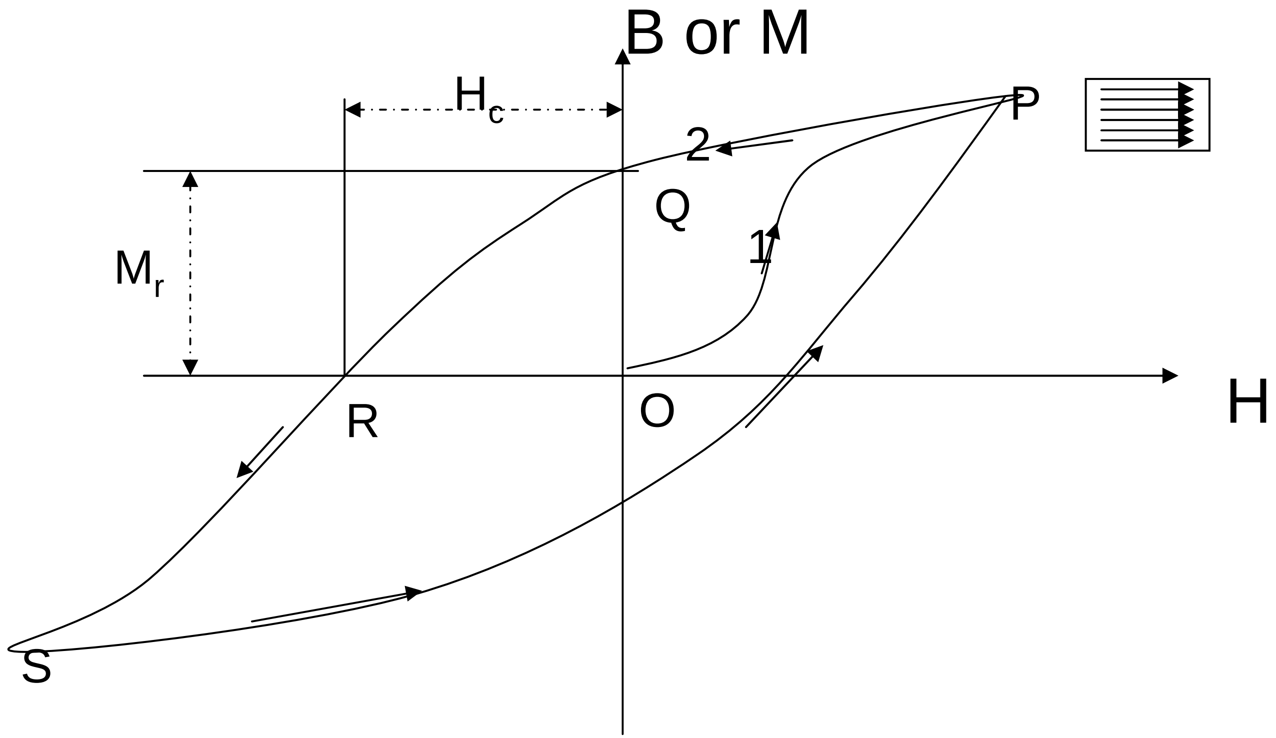
As we proceed with the negative H, values, M comes back to its initial value of zero only at certain magnitude of the reversed field H_c. H_c is known as the coercivity of the specimen. Going further the saturation of magnetization is reached in the opposite direction.

The remaining part of the loop follows. In one cycle of operation the complete loop can be obtained. This loop does include some area. The area indicates the amount of energy wasted in one cycle of operation.

SOFT AND HARD MAGNETIC MATERIALS

Hard Magnetic Materials:-

Ferromagnetic materials are classified as soft or hard. The classification is mainly based on the hysteresis characteristics. Magnetically soft materials have low coercivity (H_C) while those with high values of H_C are called hard magnetic materials.



Characteristics of Hard Magnetic materials:

Large hysteresis loop area-indicating high energy loss.

High remanent magnetization

High coercivity

High saturation flux density

Low initial permeability

Low permeability

Low susceptibility

Hard magnetic materials are used to manufacture permanent magnets:-

Magnets materials:- For permanent magnet applications, movement of domains walls is to be suppressed such that one magnetized, they remains in that state. This is achieved by using very fine single domain particles. Amongst the common magnet materials in use are carbon and alloy steel, Alnico alloys and hard ferrites. Special alloys like *Pl-CO*, manganese bisumthide and cobolt-rare earths are used in special cases where size and performance are importance.

Magnetic steels:- Caron and other slightly soluble atoms in iron precipitate out as an ordered phrase. In these materials domain walls are anchored. This leads to high values of HC. They are used in hysteresis motors

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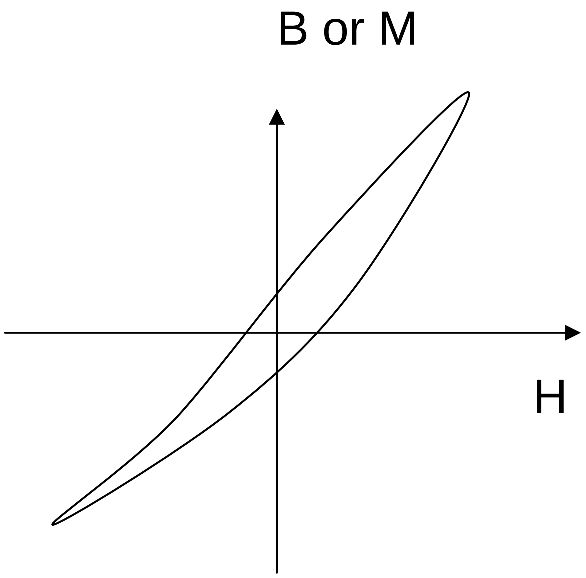
Fine particle alloys:- Elongated single domain particles of ion alloys have been with high HC which are used in battery powdered unit watch, hearing aids, space applications.

Soft Magnetic materials:-

These materials are characterized by:

1. Low permanent magnetization
2. Low coercivity
3. Low hysteresis energy loss
4. High permeability and
5. High susceptibility



In these materials domain wall motion occurs very easily. Consequently, coercive force is small. The area of the hysteresis loop is small indicating low-energy loss. These materials can be easily magnetized and demagnetized.