UNIT-04

LAQ'S

Q1.a)State Ionic polarization? Deduce the expression for ionic polarization?

b) Define electronic polarization? Derive expression for electronic polarization?

Q2.a)Discuss the frequency and temperature dependence on dielectric polarization?

b)What is meant by dielectric polarization? Classify different types of dielectric polarization?

Q3.a) illustrate the structure of barium titanate?

b) List out few applications of Ferro electric materials?

SAQ'S

Q1) Define Ferro electricity?

Q2) Draw the structure of barium titanate?

Q3) Classify the different mechanisms of dielectric polarizations?

Q4) what is meant by spontaneous polarization?

Q5) State Magnetic Susceptibility and Magnetic Permeability.

Q6) Mark the points in the Hysteresis curve

i) Residual magnetism ii) Co- ercivity

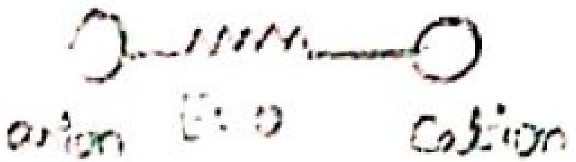
Q7) Distinguish between Soft and Hard Magnetic materials?

Q8) Write down few applications of Ferrites?

Q9) Draw the structure of Ferrites indicating Lattice sites (A,B)?

(ii) Ionic Polarization

Laq's 1a)



When external electric ~~field~~ field is applied to the ionic solid displacement of cation & anion takes place in opposite direction of the applied field this phenomena is said to be ionic polarization.

Expression of Ionic polarization

Let us consider the ionic solid which contains of one cation and one anion per unit cell when external electric field is applied to the ionic solid it is observed that cation is displaced to right hand side by x_1 and anion is displaced to ~~top~~ left hand side by x_2. The resultant dipole moment per unit cell is given as

$$p = e(x_1 + x_2) \rightarrow (1)$$

$F = K_i x_i$ $i = 1, 2, 3, \ldots n$

If $i = 1$

$F = K_1 x_1 \Rightarrow x_1 = \frac{F}{K_1}$

If $i = 2$

$F = K_2 x_2 \Rightarrow x_2 = \frac{F}{K_2}$

$$\therefore p = e\left(\frac{F}{K_1} + \frac{F}{K_2}\right) \rightarrow (2)$$

$\because$ $F = eE$ & also

$K_1 = m\omega_0^2$ $m \rightarrow$ mass of cation

$K_2 = M\omega_0^2$ $M \rightarrow$ mass of anion

$\omega_0 \rightarrow$ angular frequency

$\therefore$ Substituting K_1, K_2 & F values in eq^n (2)

The total polarization

$P = N\alpha E$ (Mathematical definition of polarization)

$$\because p = e\left(\frac{eE}{m\omega_0^2} + \frac{eE}{M\omega_0^2}\right)$$

The resultant polarization of Dielectric material which contain 'N' number of ions

$$P_i = N\left(e^2\left(\frac{1}{m\omega_0^2} + \frac{1}{M\omega_0^2}\right)\right)E_{\text{Local field}}$$

$$\because \alpha_i = e^2\left(\frac{1}{m\omega_0^2} + \frac{1}{M\omega_0^2}\right)$$

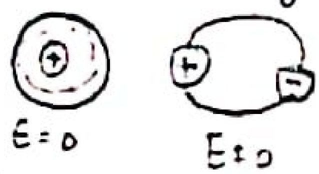
Ex :- NaCl, KCl

iii) Dipolar polarization / Orientation polarization gation/ space-charge polarization

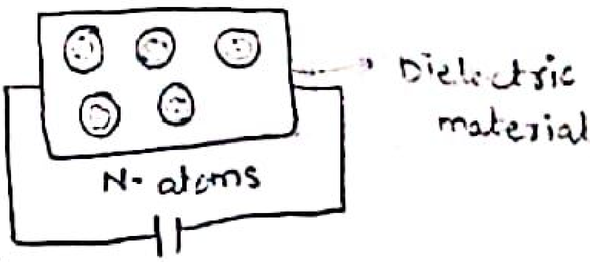
(i) **Electronic Polarization:**

1b) ~~The~~ When external electric field is applied to a dielectric ~~diect~~ material polarization occurs, displacement of positive charge nucleus and negative charge electron cloud in the opposite direction ~~takes place~~. Such polarization is said to be E.P.

Ex: Diamond, Phosphorus.



Expression for Electronic Polarization



Let us consider the atom 'A' whose atomic number "Z". If the nucleus in the atom posses the charge 'Ze'. ~~Then~~ when external electric field is ~~apply~~ applied to the dielectric material. The +ve charge nucleus & -ve charge electron cloud displaces and this displacement continous until force due to local electric field balances the separation.

At equilibrium

$F_{col} = F_{Local\ Field} \rightarrow (1)$

$\because F_{Local\ Field} = q\, E_{local\ field} \rightarrow (2)$

$q = Ze$
Charge nucleus

Using equation → (2)

eq -(2) can be re written as

$F_{Local} = (Ze)\, E_{local\ field}$ → (2)

Now using

$$F_{col} = \frac{q \cdot Q}{4\pi \varepsilon_0 d^2} \rightarrow (3) \quad [\because q = Ze]$$

Q → Effective -ve charge

$$\rho = \frac{mass}{volume} \simeq charge \Rightarrow \rho = \frac{charge}{volume} \Rightarrow \rho \cdot volume = Q$$

$$Q = \rho\ volume \Rightarrow Q = \frac{Ze}{\frac{4}{3}\pi r^3} \times \frac{4}{3}\pi d^3 \Rightarrow Q = Ze \left(\frac{d^3}{r^3}\right)$$

Volume of Sphere

Now

Substituting the value of Q in eq -(3)

$$F_{col} = \frac{(Ze)\ Ze\left(\frac{d^3}{r^3}\right)}{4\pi \varepsilon_0 d^2} \Rightarrow F_{col} = \frac{(Ze)(Ze) \cdot d}{4\pi \varepsilon_0 r^3} \rightarrow (4)$$

Now using eq (1)

$$\frac{(Ze)(Ze) \cdot d}{4\pi \varepsilon_0 r^3} = (Ze)\, E_{Local\ field} \Rightarrow (Ze) \cdot d = 4\pi \varepsilon_0 r^3 E_{Local\ Field}$$

$\mu = q - r$ (Dipole moment) $\quad p = \frac{\mu}{V} \Rightarrow p = \mu$

$\therefore p = 4\pi \varepsilon_0 r^3 E_{Local\ field}$ (Single atom)

$\therefore$ The total polarization for dielectric material which contains 'N' No. of atom

$$P = N(4\pi \varepsilon_0 r^3)\, E_{Local\ Field}$$

Now where $\alpha_e = 4\pi \varepsilon_0 r^3$

2a)

✅ 1(a) Frequency and temperature dependence of dielectric polarization

Formula for polarization:

$$P = \epsilon_0 \chi_e E$$

P = polarization,

ϵ_0 = permittivity of free space,

χ_e = electric susceptibility,

E = electric field.

Frequency dependence

- As **frequency decreases**, more polarization mechanisms become active:
  - Electronic polarization → always present (even at high frequencies).
  - Ionic polarization → active at lower frequencies.
  - Orientation polarization → appears in low-frequency (microwave) range.
  - Space charge polarization → only significant at very low frequencies (Hz-kHz).

- As **frequency increases**:
  - Space charge polarization vanishes first.
  - Orientation polarization disappears in the microwave range.
  - Ionic polarization stops in infrared.
  - Only electronic polarization remains at optical frequencies and disappears in UV.

Temperature dependence

- **Electronic & ionic polarization**: almost independent of temperature.
- **Orientation polarization**: decreases with temperature due to thermal agitation.

$$P = \frac{Np^2E}{3kT}$$

2b)

Dielectric Polarization

Dielectric polarization is the alignment of electric dipoles within a dielectric material when an external electric field is applied. This causes slight displacement of charges, reducing the effective field inside the material. There are different types of polarization based on how dipoles are formed.

1. Electronic Polarization

Occurs when the electron cloud in an atom shifts slightly relative to the nucleus under an electric field. It is very fast and occurs in all materials, especially at high frequencies.

2. Ionic Polarization

Happens in ionic solids due to the relative displacement of positive and negative ions under an electric field. Common in materials like NaCl.

3. Orientation (Dipolar) Polarization

Takes place in polar molecules with permanent dipoles (e.g., water). These dipoles align with the field, especially at microwave frequencies.

4. Space Charge Polarization

Results from the accumulation of charges at defects or interfaces within the material. It occurs at low frequencies and in impure or heterogeneous materials.

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Results from the accumulation of charges at defects or interfaces within the material. It occurs at low frequencies and in impure or heterogeneous materials.

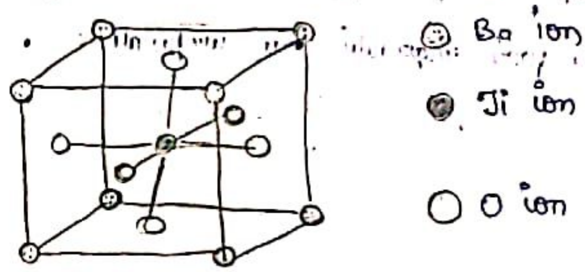
5. Interfacial Polarization (Maxwell–Wagner)

Similar to space charge, but occurs at boundaries between different materials or phases. It's significant at very low frequencies in composite materials.

3a)

1. Explain the Structure of Barium Titanate and write its applications

A) The structural changes in Barium titanate ($BaTiO_3$) crystal due to lattice variation give rise to Ferroelectricity. Above Curie temperature (approx. 120°C), $BaTiO_3$ has a cubic crystal structure with Barium ions are the corners the Titanium ions exactly at the body center, and Oxygen ions are at the face centres. At these temperatures, there is no spontaneous dipole moment



Structure in Cubic Phase (above 120°C)

- Lattice type: Simple Cubic (Perovskite-type ABO_3)
- Symmetry: Highly symmetrical cubic structure
- Unit cell arrangement.
  - i) Corner -> Ba^{2+} ions
  - ii) Centre -> Ti^{+4} ions
  - iii) Face centres: O^{2-} ions (on each face of the cube)

- The Ti^{+4} ion is perfectly centered in the cubic phase -> No net dipole moment
- The phase is paraelectric, meaning there is no spontaneous polarization.

Applications of Barium Titanate

1. Capacitors: Used in ceramic capacitors due to its high dielectric constant
2. Piezoelectric Devices: Used in microphones, speakers, and ultrasonic transducers
3. Non-volatile Memory Devices: Used in Fe RAM (Ferroelectric RAM)
4. Thermistors: Used for temperature sensing
5. Electro-optic Applications: Used in optical modulators and light valves

6. Biomedical : use in bone graft materials and bio-sensors, due to its biocompatibility, and piezoelectricity

7. Tunial Devices: BaTiCO$_3$ thin films are used in tunable capacitors, filters and phase shifters, in microwave communications

3b)

Applications of Ferroelectric Materials:

1. **Non-volatile memory devices (FeRAM):**
   Used in ferroelectric random access memory, which retains data without power.

2. **Capacitors:**
   Ferroelectric materials like $BaTiO_3$ are used in high-permittivity capacitors.

3. **Piezoelectric devices:**
   Used in sensors, actuators, and ultrasonic transducers due to their piezoelectric behavior.

4. **Electro-optic devices:**
   Employed in light modulators and switches in optical communication systems.

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5. **Tunable RF components:**
   Used in tunable microwave filters and phase shifters for telecommunications.

6. **Pyroelectric sensors:**
   Applied in infrared detectors, motion sensors, and thermal imaging.

Saq's

Q1) Define Ferroelectricity:

Ferroelectricity is the property of certain dielectric materials to exhibit **spontaneous electric polarization** that can be **reversed by applying an external electric field**. This behavior is similar to ferromagnetism, but with electric dipoles.

Q2) Draw the Structure of Barium Titanate ($BaTiO_3$):

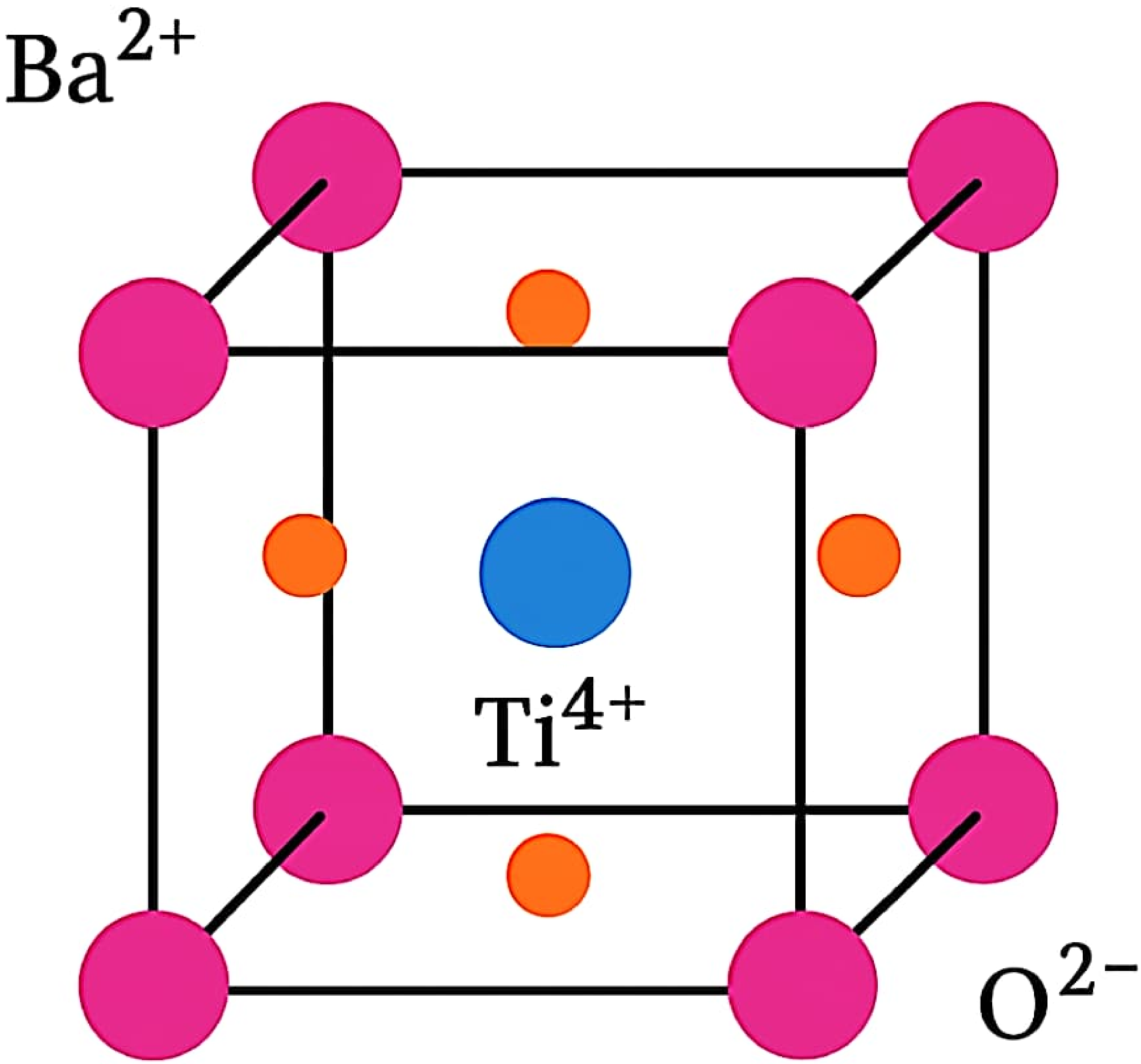
Since I can't draw directly here, here's a description:

- **Crystal Type:** Perovskite structure
- **Arrangement:**
  - Barium (Ba^{2+}) ions at the corners of the cube

Q2) Draw the Structure of Barium Titanate ($BaTiO_3$):

Since I can't draw directly here, here's a description:

- **Crystal Type:** Perovskite structure
- **Arrangement:**
  - Barium (Ba^{2+}) ions at the corners of the cube
  - Oxygen (O^{2-}) ions at the face centers
  - Titanium (Ti^{4+}) ion at the center (displaced in ferroelectric phase)
  - This displacement of Ti^{4+} causes spontaneous polarization.



Barium Titanate

Q3) Classify the Different Mechanisms of Dielectric Polarizations:

1. **Electronic Polarization** – Shift of electron cloud in atoms.
2. **Ionic Polarization** – Displacement of ions in ionic crystals.
3. **Orientation (Dipolar) Polarization** – Alignment of permanent dipoles.
4. **Space Charge Polarization** – Charge accumulation at interfaces or defects.
5. **Interfacial Polarization** – Charge build-up at material boundaries.

Q4) What is Meant by Spontaneous Polarization?

Spontaneous polarization is the **natural alignment of electric dipoles** in a ferroelectric material **without any external electric field**. It arises due to structural asymmetry in the crystal.

Q5) State Magnetic Susceptibility and Magnetic Permeability:

- **Magnetic Susceptibility (χ):**
  It is the ratio of magnetization (M) to the applied magnetic field (H):

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

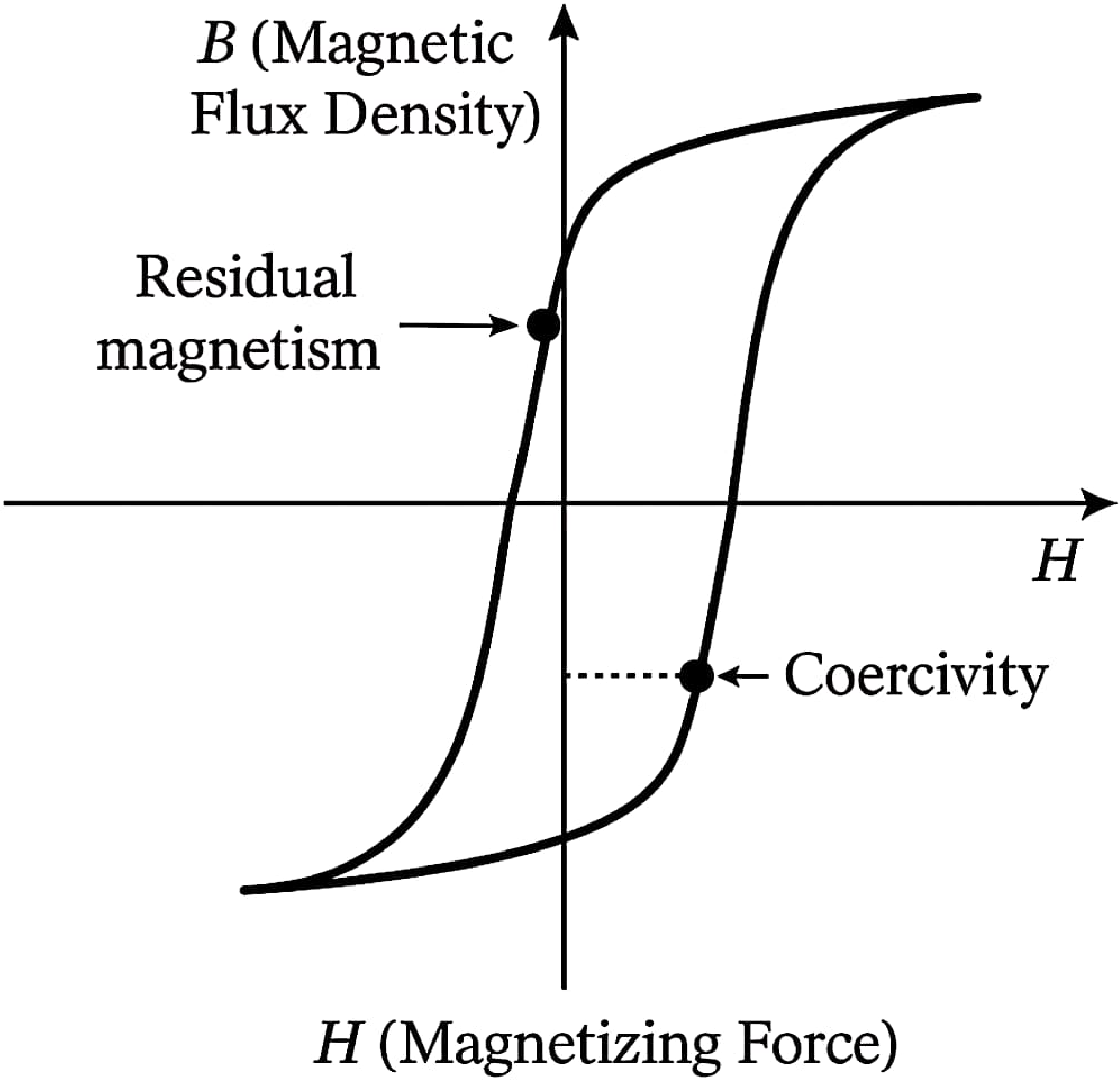
- **Magnetic Permeability (μ):**
  It is the measure of how easily a material can be magnetized:

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

Q6) Points on the Hysteresis Curve:

- **i) Residual Magnetism (Remanence):**
  The value of magnetization (M) or magnetic flux density (B) that remains **after the external magnetic field (H) is reduced to zero.**
  → Found on the vertical axis where H = 0.

- **ii) Coercivity (Coercive Field):**
  The value of the reverse magnetic field (H) required to bring the magnetization (M) or flux density (B) **back to zero** after saturation.
  → Found on the horizontal axis where B = 0.


B (Magnetic
Flux Density)
Residual
magnetism
H
Coercivity
H (Magnetizing Force)

Q7) Distinguish between Soft and Hard Magnetic Materials:

Property	Soft Magnetic
Coercivity	Low
Hysteresis Loss	Low
Retentivity	Low
Applications	Transformers, electromagnets

Q7) Distinguish between Soft and Hard Magnetic Materials:

agnetic	Hard Magnetic
	High
	High
	High
ɔrmers, magnets	Permanent magnets

Q8) Write Down Few Applications of Ferrites:

- Used in transformer cores and inductors
- High-frequency applications (radio antennas)
- Microwave devices
- Magnetic recording heads
- EMI suppression in electronic circuits

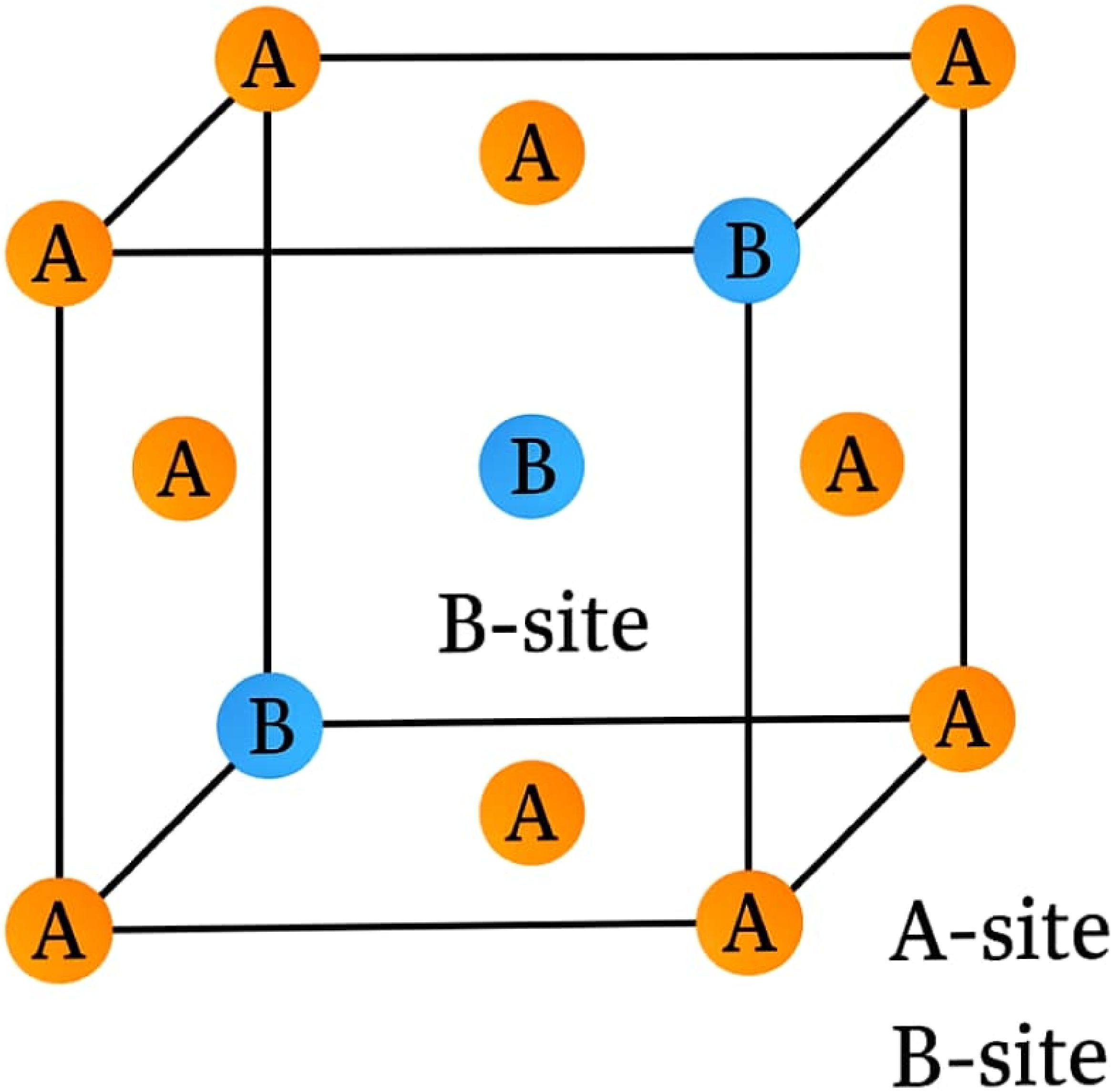
Q9) Draw the Structure of Ferrites Indicating Lattice Sites (A, B):

Ferrites have a **spinel structure** with two types of lattice sites:

- **A-site (Tetrahedral):** Occupied by metal ions in 4 oxygen surroundings
- **B-site (Octahedral):** Occupied by metal ions in 6 oxygen surroundings

General Formula:

$$MFe_2O_4 \quad (M = divalent metal like Zn, Mn, Co, etc.)$$



Ferrites