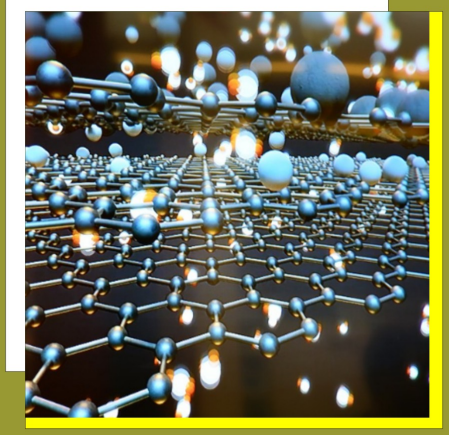
MATERIAL SCIENCE



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ELECTRONICS ENGINEERING-ECE

STUDY MATERIAL

MATERIAL SCIENCE

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ELECTRONICS ENGINEERING

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STUDY MATERIAL

MATERIAL SCIENCE

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CHAPTER-1
INTRODUCTION ENGINEERING MATERIALS

Introduction:

The properties of material may be characterized by some factors such as the electrical conductivity, coefficient of expansion, magnetic permeability, dielectric constant etc. These quantities are functions of parameters, such as temperature, pressure, frequency of applied field etc.

Material science is branch of applied science under this we study the relationship between structure of materials and its properties.

Wave/ particle duality:

Wave / particle duality is expressed by the well knownde Broglie relationship.

$\lambda = h/p = h/m\vartheta$

λ = effective wave length

p = momentum whose mass is 'm' and velocity ϑ .

h = plank's constant $\left(h = 6.62\times10^{-34}\ \text{J-S}\right)$

Quantized Energies:

- The energies of particles and waves can assume only certain fixed or quantized values.
- For photons ;

$$E = h\upsilon = \frac{hc}{\lambda}$$

h = plank's constant = 6.62×10^{-34}J-S

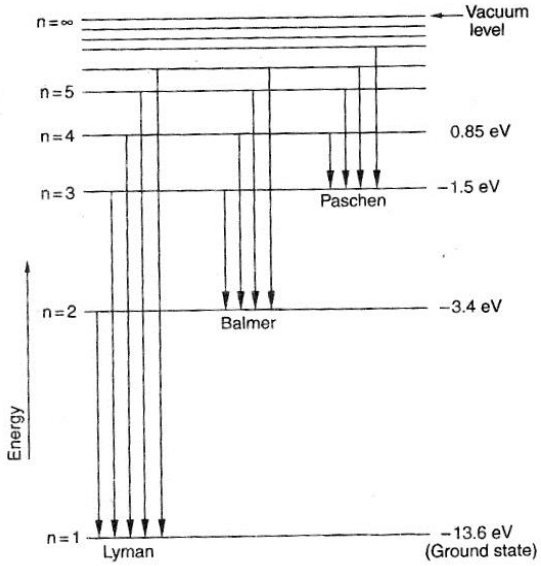
C = speed of light = 2.998×10^{8} m/s

λ = wave length

- Energy levels (E) given of Bohr theory as :

$$E = \frac{-2\pi^2 m_e q^4}{h^2 n^2} = \frac{-13.6}{n^2}\ \text{ev}\ ,\ n = 1,2,3.....$$

- If energies of electrons are lower, they are closer to the nucleus.



Electron energy level in hydrogen atom.

The ground state corresponds to the electrons level n=1, with E=-13.6eV. For the $n = \infty$ level, corresponding to E=0, the electron has gained the 13.6eV energy needed to ionize hydrogen

The Pauli Principle:

The electron by dynamics within all atoms is characterized by four quantum numbers n, l, m_l, m_S.

n = principle quantum number.

l = orbital quantum number (azimuthal quantum number).

m_l = magnetic quantum number.

m_S = Spin quantum number.

- The principle quantum number n of an electron in an atom determines major energy levels.
- The quantum number *l* determines the angular momentum of the electron.

range of $l \Rightarrow 0 < l < (n\text{-}1)$

For n = 1, l = 0

For n = 2, l = 0, 1

- The magnetic quantum number m_l determines the possible quantized space orientations of the orbital angular momentum.
  range $-l \rightarrow o \rightarrow l$
- Total $(2l+1)$ value possible.
- If electrons were spinning about its own axis as well as in orbit about the nucleus then it is reveals by the spin quantum number m_s.
- There are two possible directions of spin assigned

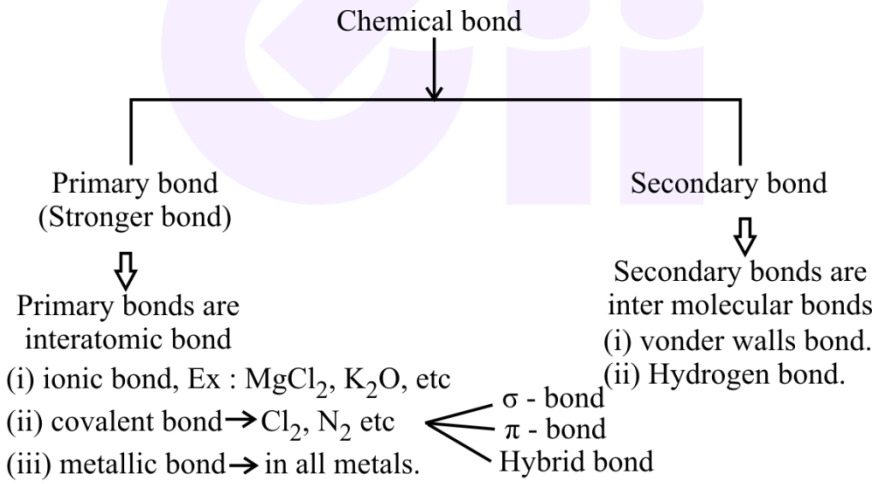
As $m = +\frac{1}{2}, -\frac{1}{2}$

Pauli Exclusion Principle:

- In an atom it is not possible to exist two electrons in an exactly same state as defined by all four quantum numbers.
- Maximum possible number of electrons with 'n' is $2n^2$

Bonding in solids:

- Atoms are bonded or linked to other atoms in some manner as a result of interatomic forces.
- These binding forces between atoms are called chemical bonds.



- **Arrangement of atom in materials**:
  Classification on the basis of atomic grouping:
  (i) Molecular structures.
  (ii) Crystal structures.
  (iii) Amorphous structures.

- **Molecular structures** –In this type of structure there are distinct number of atoms that are held together by primary brands, Ex: O_2, H_2O, C_2H_4 etc.

- **Crystal structure**: In this the atoms are arranged in a regular geometrical arrays called as space lattice. Ex: solid materials and most minerals.

- **Amorphous structures**: The atoms have a certain local order but, when we considered as an aggregate, have a more disorganised atom compared to crystalline solid.

SOLID STRUCTURES:

- Unit cell
- Lattice

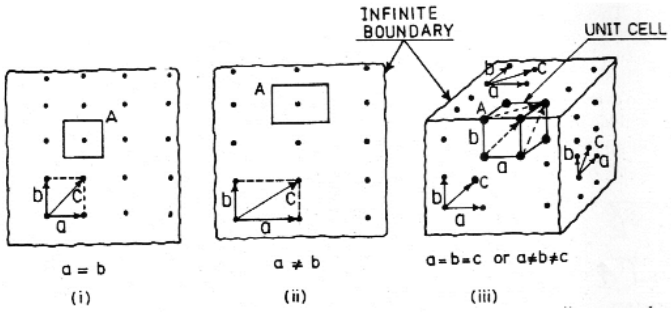
Unit cell: Unit cell can be defined as minimum area cell in 2-dimension & minimum volume cell in 3-dimension by repetition of which a crystal or lattice can be formed.

- It is analogous to a brick used in the building construction.

Parameters of unit cell

1. Dimension of unit cell.
2. No. of atoms per unit cell.
3. Angle between axis
4. Co-ordination number.
5. Atomic packing factor.

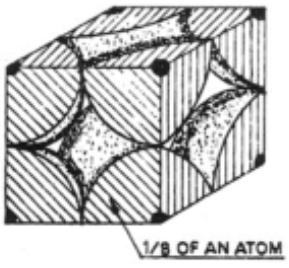
Lattice: A periodic or an infinite array of points in 3-dimensional space or orderly arrangement of unit cell is known as lattice.



Two-dimensional space lattices (i) square, (ii) rectangular, and (iii) three-dimensional space lattice.

Cubic crystal structure: There are mainly 4 cubic crystal structures:

Simple cubic crystal structure (SCC):

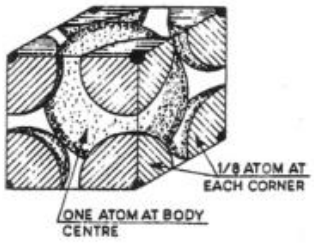


- There are 8 atoms at 8 corners of the cube.
- Corner atoms touch each other.
- No. of atoms per unit cell = $8 \times \frac{1}{8} = 1$
- Coordination number $\Rightarrow$
  It is defined as no. of nearest and equidistant atoms with respect to any other atom in a unit cell.
- Co-ordination number in SCC = 6
- Atomic packing factor (APF) = $\frac{\text{Total volume of the atoms per unit cell}}{\text{Volume of the unit cell}}$
- It is also known as packing efficiency (η).

- $APF = \frac{N \times \text{Volume of each sphere}}{\text{Total volume of each cell}}$
- $APF = \frac{1 \times \left(\frac{4}{3}\right)\pi r^3}{a^3} = 0.52$ $\quad a = 2r$

Body centred cubic structure (BCC):

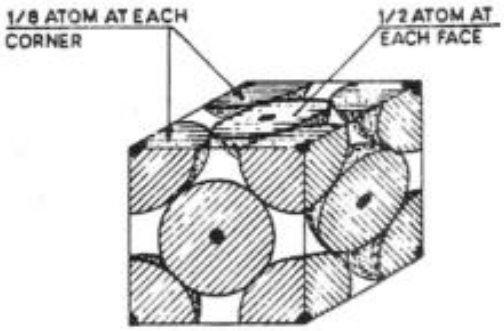
- In BCC there are 8 atoms at each corners of the unit cell and one atom is at centre of the unit cell.
- Two atoms touch along body diagonal.
- No. of atoms per unit cell = $8 \times \frac{1}{8} + 1 = 2$
- Coordination number = 8



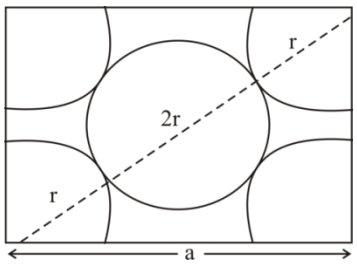
- $APF = \frac{2 \times \frac{4}{3}\pi r^3}{a^3} = 0.68$
- $r = \frac{a\sqrt{3}}{4}$

Face centred cubic. (FCC):

- In FCC there are 8 atoms at 8 corners of the cube and 6 atoms at the centre of 6 faces of the cube/ unit cell.



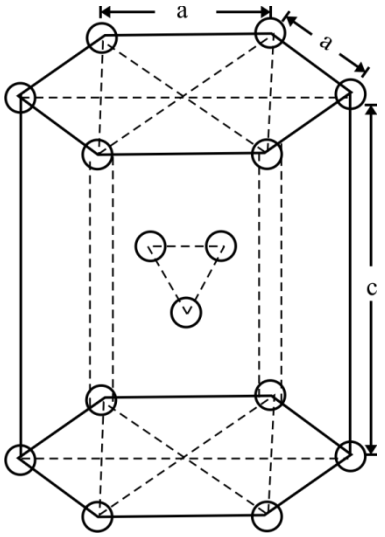
- Two atoms touch along face diagonal.



$$r = \frac{a}{2\sqrt{2}}$$

- Numbers of atom per unit cell = $8 \times \frac{1}{8} + 6 \times \frac{1}{2} = 4$
- Coordination number = 12
- $APF = \frac{4 \times 4/3\pi r^3}{a^3} = 0.74$

- FCC also known as cubic closed packed (CCP).

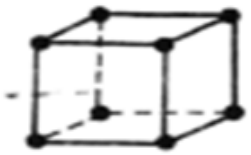
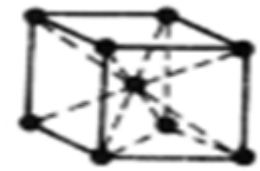
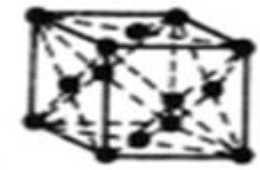
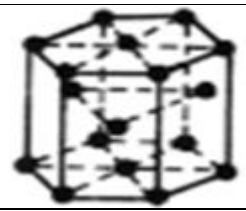


Diamond cubic (DC):

- There are 18 atoms in DC.
- 8 atoms at 8 corners of the cube/ unit cell.
- 6 atoms at centre of six faces.
- 4 atoms are inside.
- No. of atoms per unit cell = $8\times\frac{1}{8}+6\times\frac{1}{2}+4=8$
- Structure is also known as tetrahedral structure.
- Co-ordination number = 4
- APF = 0.34
- $r=\frac{a\sqrt{3}}{8}$

Hexagonal closed packing (HCF):

- No. of atoms per unit cell $=12\times\frac{1}{6}+2\times\frac{1}{2}+3=6$
- APF = 0.74
- Coordination number = 12
- **Graphite:**It is hexagonal but not close pack or HCP as there is no central atom in the top or bottom hexagonal.

Lattice structure	Unity cell schematic	Number of nearest neighbour	Packing efficiency	Typical metals
Simple cubic		6	52%	None
Body-centered cubic		8	68%	Fe, Cr, Mn, Cb, W, Ta, Ti, V, Na, K
Face-centered		12	74%	Fe, Al. Cu, Ni, Ca, Au, Ag, Pb, Pt
Hexagonal close-packed		12	74%	Be, Cd, Mg, Zn, Zr

Comparison of different crystal structures

Mechanical properties	Strength , stiffness , elasticity , plasticity, ductility , toughness, hardness, brittleness, malleability, etc.

Thermal properties	Specific heat , thermal expansion, thermal conductivity , etc.
Electrical properties	Conductivity , resistivity, dielectric permembility, dielectric strength , etc.
Magnetic properties	Permeability, coercive force, etc.
Physical properties	Dimensions, density, porosity, structure, etc.
Chemical properties	Corrosion resistance , acidity, composition oxidation, etc.
Optical properties	Colour, light transmission, light reflection, etc.
Acoustical properties	Sound transmission, sound reflection, etc.

Example: 1

Total number of electrons that can be accommodated in various electron states in a Valance band of a given solid is equal to- **IES – 2001**

(a.) Atomic number of solid (b.) Half the number of atoms in the solid

(c.) The number of atoms in the solid (d.) Twice the number of atoms in the solid.

Solution: (a)

Example: 2

Which of the following is/are true for the diamond structure? **IES – 2009**

1. Coordination number is four
2. Packing fraction is 0.34
3. Copper crystallizes into diamond structure.
4. Lattice is FCC.

(a.) 1 only (b.) 1, 2 and 4

(c.) 2 and 3 (d.) 2, 3 and 4

Solution: (b)

Lattice is Diamond cubic or tetrahedral.

Example: 3

When BCC iron is heated, it change to FCC iron resulting in- **IES-2002**

(a.) Contraction in volume (b.) increase in volume.

(c.) No change in volume (d.) crack in the material

Solution: (a)

$$\text{in BCC} \rightarrow r = \frac{a\sqrt{3}}{4}$$

$$\text{in FCC} \rightarrow r = \frac{a\sqrt{2}}{4}$$

$\therefore$ Volume of atom $= 4/3\pi r^3$

$\therefore$ Volume of FCC < Volume of BCC

So, there is contraction in volume.

CHAPTER-2
DIELECTRIC PROPERTIES OF MATERIAL

Dielectric materials:

- These are the insulating materials in which the valance electrons are tightly bound to their parent atoms.
- Dielectric is non-conducting material which can be polarized i.e exhibit an electric dipole by applying an external electric field.
- They require a very large electric field to remove valance electrons from the atoms.
- Example: mica, Bakelite, elastomeric fibre, transformer oil, silicon oil, varnishes, air, N_2, O_2 .etc.

SALIENT PROPERTIES:

- Dielectric constant
- Dielectric loss.
- Dipole moment
- Polarization
- Polarizability

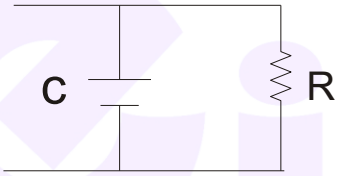
Dielectric constant (ε): The electric field strength E in any point of space, i.e. the force per unit charge, is related to the flux density (D) in that point by –

$$\boxed{\overline{D}=\varepsilon_o\varepsilon_r\overline{E}}$$

$\varepsilon_o = 8.854\times10^{-12}$ farad m^{-1}

ε_r = relative permittivity

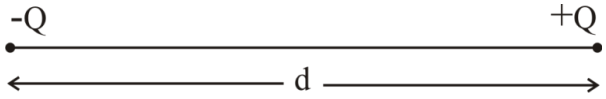
Dielectric loss:



$$\text{Loss factor} = \frac{1}{\omega RC} = \tan\delta.$$

Dipole moment:

- If two charges of equal magnitude but opposite polarity are separated by distance 'd' then dipole moment



$$\boxed{\overline{p}=Qd}$$

- If point charges Q_1 , Q_2, Q_3……..Q_n then dipole moment with respect to Neutral is

$$\boxed{\overline{p}=\sum_i Q_i r_i}$$

- When the net charge of the system is zero $\left(\sum Q_i=0\right)$, this definition is independent of the choice of origin. If the origin is displaced by on amount Δr , the new value of dipole moment is

$$\overline{p}+\overline{\Delta p}=\sum Q_i(r_i+\Delta r)=\sum Q_i r_i+\Delta r\sum Q_i=\overline{p}$$

$$\left(\therefore \Sigma Q_i = 0\right)$$

- Dipole moment is a vector quantity which is directed from negative to positive charge.
- Unit for the dipole moment is **debye**

- 1 debye=3.335 x 10^{-30} coulomb - meter
  OR
  1 debye=1 x 10^{-18} E.S.U - cm

NOTE: $\overline{D} = \varepsilon \overline{E}$, this relation valid only for isotropic material. This relation is not valid for anisotropic material for such material dielectric constant replaced by a *Tensor quantity*.

Polarization: Polarization can be defined as the electric dipole moment per unit volume.

$$\text{Polarization, } \overline{P} = \frac{\overline{p}\,(\text{dipole moment})}{\text{volume}}$$

Or $\boxed{\overline{P} = N\overline{p}}$

Where N = Number of molecules per unit volume of a material.

Also $\boxed{\overline{P} = \varepsilon_o \chi_e \overline{E}}$

χ_e = electric susceptibility

E = electric field.

$\chi_e \Rightarrow$ It is defined as the ability of material to become polarized and it varies from one material to another.

- Polarization produces a secondary field E_s, such the

$$E_s = \frac{-P}{\varepsilon_o} \quad \text{(Opposite to the applied field)}$$

Total field in the Dielectric : $E = E_o + Es$

where E_o = *externally applied field*

$$\overline{E} = \overline{E_o} - \frac{\overline{P}}{\varepsilon_o}$$

Or $\varepsilon_o \overline{E_o} = \overline{P} + \varepsilon_o \overline{E} = \overline{D}$ $\quad \{ D = \text{flux density})$

$$\varepsilon_o \overline{E_o} = \varepsilon_o \chi_e \overline{E} + \varepsilon_o \overline{E} \qquad \{\because \overline{P} = \varepsilon_0 \chi_e \overline{E})$$

$$\boxed{\overline{E} = \frac{\overline{E_o}}{1+\chi_e}}$$

$$\overline{D} = \varepsilon_o \overline{E} + \varepsilon_o \chi_e \overline{E}$$

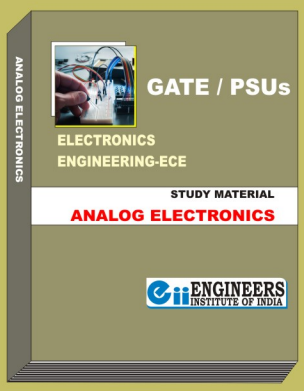
$$\overline{D} = \varepsilon_o (1+\chi_e) \overline{E}$$

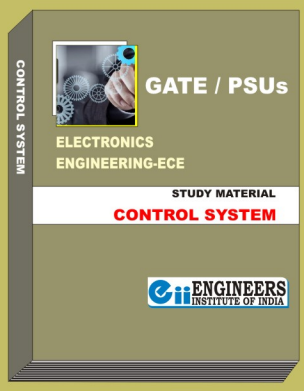
$$\overline{D} = \varepsilon_o \varepsilon_r \overline{E}$$

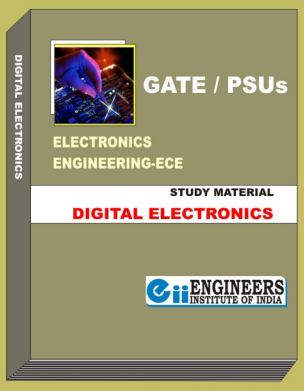
$$\boxed{\varepsilon_r = 1 + \chi_e}$$ $\quad \varepsilon_r$ = relative permittivity

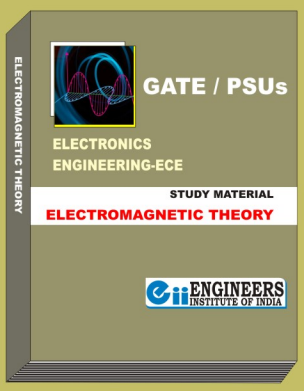
Material	Relative Permitivity
Air	1.0006
Paper	2.0-3.0

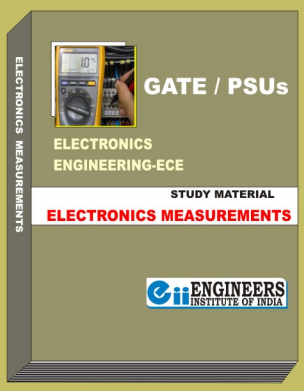
Published Books

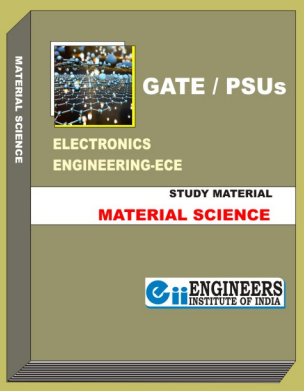


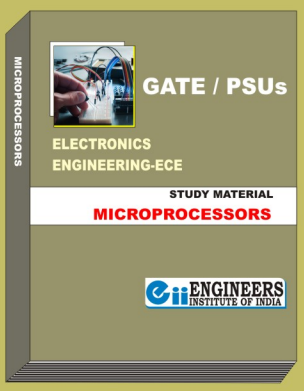


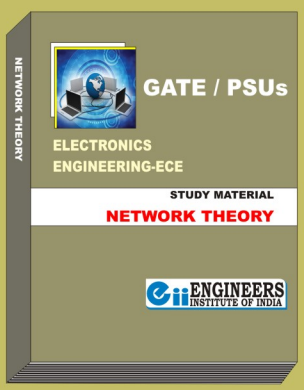


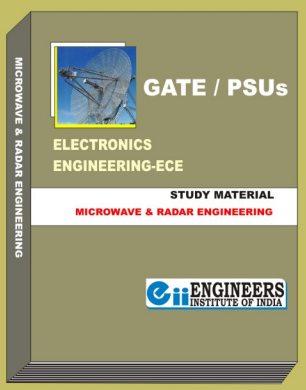


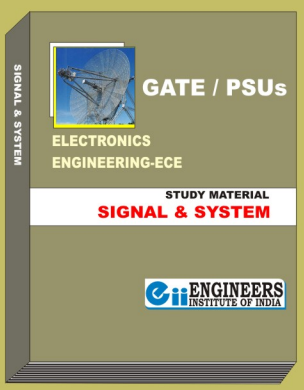












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Bakelite	4.9
Mica	6
Dry earth	5
Titanium dioxide	100
Distilled water	81

Polarizability: It measures the electric capability of the particle *i.e.* Average dipole moment per unit field strength.

$$\overline{P} = \alpha \overline{E}$$

α = Polarizability $\quad (unit = farad - m^2)$

$$\alpha = \frac{\varepsilon_o \chi_e}{N} = \frac{\varepsilon_o (\varepsilon_r - 1)}{N}$$

Dielectric Strength: The maximum value of field intensity that a dielectric can sustain without break down is called its dielectric strength.

Dielectric strength of a material is an intrinsic property of the bulk material and is dependent on the configuration of the material or the electrodes with which the field is applied. At breakdown, the electric field frees bound electrons. If the applied electric field is sufficiently high, free electrons may become accelerated to velocities that can liberate additional electrons during collisions with neutral atoms or molecules in a process called avalanche breakdown. Breakdown occurs quite abruptly (typically in nanoseconds), resulting in the formation of an electrically conductive path and a disruptive discharge through the material. For solid materials, a breakdown event severely degrades, or even destroys, its insulating capability.

Factors affecting dielectric strength

- It increases with the increase in thickness of the specimen. (Directly proportional)
- It decreases with the increase in operating temperature. (Inversely proportional)
- It decreases with the increase in frequency. (Inversely proportional)
- It decreases with the increase in humidity. (Inversely proportional)

Material	Dielectric strength MV/m
Air	3
Mineral Oil	15
Impregnated paper	15
Polystyrene	20
Rubber	21
Bakelite	25
Glass	30
Mica	300

Note: Properties of an isotropic material are independent of direction. Generally if molecular structure of a material is randomly oriented will be isotropic while if materials have directional characteristics are said to be anisotropic. (Certain plasma are anisotropic).

Types of polarization: