ELECTRICAL ENGINEERING

ELECTRICAL MATERIALS

Comprehensive Theory
with Solved Examples *and* Practice Questions

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Electrical Materials

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CONTENTS

Electrical Materials

CHAPTER 1

Introduction to Engineering Materials Introduction 1-43

1.1 Introduction 1
1.2 Classification of Engineering Materials 1
1.3 Classification of Solids from Electrical Engineering Point of View 2
1.4 The Atomic and Electronic Structure 2
1.5 Quantized Energies 3
1.6 Bonding in Solids 3
1.7 Atom Arrangement in Materials 11
1.8 Amorphous 12
1.9 Space Lattice 12
1.10 Basis 12
1.11 Bravais Lattices 12
1.12 Unit Cell 14
1.13 Cubic Crystal Structures 15
1.14 Miller Indices 19
1.15 Planar Density 20
1.16 Interplanar Spacing 21
1.17 Properties of Engineering Materials 21
1.18 Crystal Imperfections 22
1.19 Point Imperfections 22
1.20 Line Defect 25
1.21 Surface Defect 26
1.22 Ionic Crystal Structure 28
1.23 Bragg's Law 28
1.24 Burger's Vector 31
Objective Brain Teasers 37
Conventional Brain Teasers 39

CHAPTER 2

Dielectric Properties of Materials 44-84

2.1 Dielectric 44
2.2 Homogeneity, Linearity and Isotropy 47
2.3 Types of Polarization 48
2.4 Internal Field in Solids and Liquids 54
2.5 Dielectric Strength 55
2.6 Classification of Dielectrics on the Basis of their Dielectric Behaviour 55
2.7 Another Classification Based on Special Features of Dielectric Materials 59
2.8 Dielectric in AC Fields, Complex Permittivity of Lossy Dielectrics 65
Objective Brain Teasers 69
Conventional Brain Teasers 76

CHAPTER 3

Magnetic Properties of Materials 85-117

3.1 Introduction 85
3.2 Parameters 85
3.3 Magnetic Dipole Moment 87
3.4 Classification of Magnetic Materials 89
3.5 Curie Temperature 95
3.6 Laws of Magnetic Materials 96
3.7 Domain Theory 98
3.8 Magnetisation Curve & Magnetic Hysteresis Loop 100
3.9 Magnetic Anisotropy 101
3.10 Magnetostriction 101
3.11 Villari Effect 102
3.12 Antiferromagnetic Material 102
3.13 Ferrimagnetic Materials 103

3.14 Magnetic Materials Used in Electrical Devices 105
Objective Brain Teasers 109
Conventional Brain Teasers 114

CHAPTER 4

Conductive Materials..... 118-144

4.1 Electrical Conductivity 118
4.2 Free Electron Theory of Metals-Ohm's Law 118
4.3 Joule's Law 121
4.4 Relaxation Time (τ) 121
4.5 Collision Time (τ_c) 122
4.6 Mean Free Path (λ) 122
4.7 Mean Free Path and Velocity at Fermi Level 122
4.8 Factors Affecting Electrical Conductivity (or Resistivity) of Conducting Materials 123
4.9 Relation between Temperature Coefficient of Alloys and Pure Metals 124
4.10 Application of Conducting Materials 125
4.11 Conductors for Electrical Machines 125
4.12 Thermal Conductivity of Metals-Wiedemann Franz Law 125
4.13 Thermoelectric Phenomena 126
4.14 Peltier Effect 127
4.15 Superconductivity 128
4.16 Other Properties of Superconductivity 130
4.17 Types of Superconductors 130
4.18 BCS Theory of Superconductors 131
4.19 Formation and Characteristics of Cooper Pairs 131
4.20 Applications of Superconductor 132
Objective Brain Teasers 137
Conventional Brain Teasers 141

CHAPTER 5

Semiconductor Materials 145-165

5.1 Introduction 145
5.2 Electrical Conductivity of Metals, Semiconductors and Insulators 145
5.3 Electrons and Holes in an Intrinsic Semiconductor (Pure Semiconductor) 146
5.4 Extrinsic Materials 147
5.5 Mechanism of Current Flow in a Semiconductor 148
5.6 Charge Densities in a Semiconductor 149
5.7 Electrical Properties of Semiconductors 150
5.8 Hall Effect 151
5.9 Conductivity Modulation 153
5.10 Thermistors 153
5.11 Photoconductors 153
5.12 Generation and Recombination of Charges 154
5.13 Recombination 154
5.14 Diffusion 154
5.15 Einstein Relationship 155
5.16 Total Current $\Rightarrow$ (Diffusion + Drift) 155
5.17 Electrical Properties of Semiconductor 155
5.18 Gallium Arsenide (GaAs) 158
Objective Brain Teasers 159
Conventional Brain Teasers 162

CHAPTER 6

Miscellaneous 166-178

6.1 Low Resistivity Conducting Materials 166
6.2 Solder's 166
6.3 High Resistive Materials 167
6.4 Insulating Materials 168
6.5 Basics of Nanomaterials 169
6.6 Some Important Points 175
Objective Brain Teasers 176
Conventional Brain Teasers 178

CHAPTER

1

Introduction to Engineering Materials

1.1 INTRODUCTION

Material science is a branch of applied science concerned with investigating the relationship existing between the structure of materials and their properties. It is an inter-disciplinary study of materials for entirely practical purposes.

For any kind of product every engineer is vitally concerned with the materials available to him. While making a choice of material for a particular product an engineer must be aware of basic atomic structure of the materials and take into account such properties as strength, electrical conductivity, thermal conductivity, density and others. We shall learn in this set about properties of those materials which have great importance from electrical engineer's point of view.

1.2 CLASSIFICATION OF ENGINEERING MATERIALS

From material science point of view materials may be classified under following broad groups:

(i) Metals and alloys (ii) Ceramics and glasses (iii) Organic polymers

- **Metals** are familiar objects with a characteristic appearance; they are capable of changing their shape permanently, and have good thermal and electrical conductivity.
- An **alloy** is a combination of more than one metal.
- **Ceramics and glasses** are non-metallic inorganic substances, which are brittle and have good thermal and electrical insulating properties.
- **Organic polymers** are relatively inert and light, and generally have a high degree of plasticity.

Figure lists typical examples from each of these three groups of materials. In addition, examples of materials which lie between two groups are also shown.

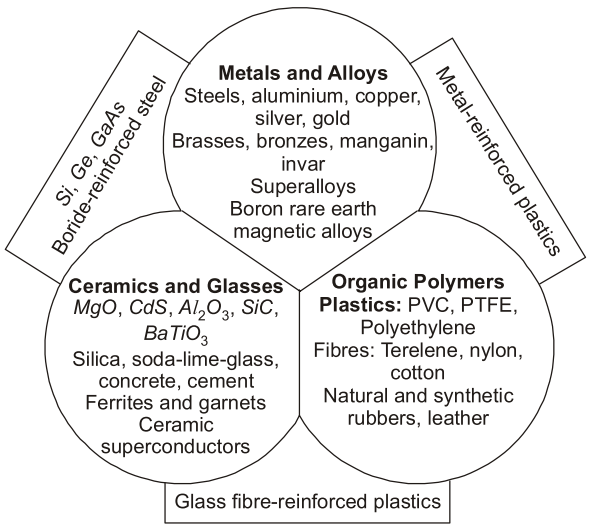


Fig. : *Three major groups of engineering materials*

OBJECTIVE BRAIN TEASERS

Q.1 The Miller indices are same for
(a) perpendicular planes
(b) crystal planes
(c) parallel planes
(d) three crystallographic axes

Q.2 When *BCC* iron is heated, it changes to *FCC* iron resulting in
(a) increase in volume of unit cell
(b) contraction in volume of unit cell
(c) no change in volume of unit cell
(d) cracks in the material

Q.3 A crystal lattice, the vacancies created by the absence of certain atoms are known as
(a) Hurtz defect (b) Pauli's defect
(c) Frankel defect (d) Schottky defect

Q.4 Consider the following statements with regard to FCC structure:
1. Number of nearest neighbour atoms is twelve.
2. Packing efficiency is 0.74.
3. There is an atom at the body centre of the unit cell.

Which of the statements given above is/are correct?
(a) 1, 2 and 3 (b) 1 and 2
(c) 2 and 3 (d) 1 and 3

Q.5 The atomic packing factor for body centric cubic is
(a) 0.52 (b) 0.62
(c) 0.68 (d) 0.74

Q.6 Match **List-I** (Atoms) with **List-II** (Corresponding Cubic Crystal Structure) and select the correct answer using the codes given below the lists:

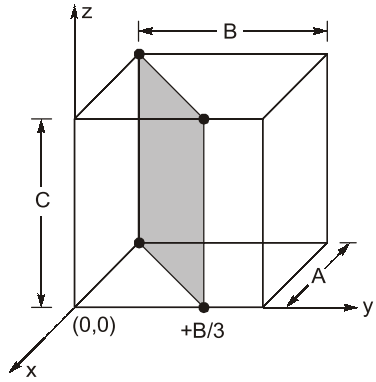
List-I :
A. Silicon
B. Gold
C. Magnesium
D. Maganese

List-II :
1. Simple cubic structure
2. Body centered cubic structure
3. Face centered cubic structure
4. Diamond cubic structure
5. Hexagonal closed packing

Codes:

	A	B	C	D
(a)	4	3	5	1
(b)	3	4	2	5
(c)	1	2	3	4
(d)	5	3	4	2

Q.7 Miller indices of the shaded figure in structure given below is



(a) $+A, \frac{B}{3}, C$ (b) $-1, \frac{1}{3}, \infty$
(c) $-A, \frac{B}{3}, \infty$ (d) – 1, 3, 0

Q.8 The unit cell of a certain type of crystal is defined by 3 vectors $\vec{a}, \vec{b}$ and $\vec{c}$. The vectors are mutually perpendicular but $a = b \neq c$. The crystalline structure is
(a) Triclinic (b) Tetragonal
(c) Monoclinic (d) Orthorhombic

Q.9 In a silicon crystal, the arrangement of atoms repeats periodically. This type of material is classified as
(a) Amorphous and non-crystalline
(b) Non-crystalline and epitaxial
(c) Epitaxial and single crystal
(d) Amorphous and single crystal

ANSWERS KEY

1. (c)	**2.** (b)	**3.** (d)	**4.** (b)	**5.** (c)
6. (a)	**7.** (d)	**8.** (b)	**9.** (c)	**10.** (c)
11. (d)	**12.** (a)	**13.** (d)	**14.** (d)	**15.** (a)
16. (d)	**17.** (c)	**18.** (b)		

HINTS & EXPLANATIONS

1. (c)

The number of open-loop poles in RHS are $P = 0$.

2. (b)

APF of BCC = 0.68

APF of FCC = 0.74

and $$APF \propto \frac{1}{\text{Volume of unit cell}}$$

4. (b)

In FCC structure, there are atoms at the centre of each face and at every corner.

7. (d)

Intercepts made by plane on 3 axis

$$\Rightarrow \quad -A, \frac{B}{3}, \infty$$

$\therefore$Miller indices

$$\Rightarrow \quad -1, 3, 0$$

9. (c)

A crystal has periodicity of atoms.

11. (d)

All of the above statements are correct.

15. (a)

Electronic polarization is independent of temperature.

16. (d)

Given lattice constant a : 8 Å

Distance between the two atoms is equivalent to nearest neighbour distance

For diamond structure

Nearest neighbour distance = $\frac{\sqrt{3}}{4}a$

Distance between two atoms

$$= \frac{\sqrt{3}}{4} \times 8 = 2\sqrt{3}\,\text{Å} = 3.46\,\text{Å}$$

17. (c)

- The smallest group of atoms which when repeated regular to form crystal is unit cell.
- Closed hexagonal space lattice is found in Cobalt, antimony and bismuth.

18. (b)

If dislocation density is high, mechanical strength of material decreases.

CONVENTIONAL BRAIN TEASERS

Q.1 Molybdenum has the BCC crystal structure, a density of 10.22 g cm^{-3} and an atomic mass of 95.94 g mol^{-1}. Find the atomic concentration, lattice parameter a, and atomic radius of molybdenum?

1. (Sol.)

- Since molybdenum has BCC crystal structure, there are 2 atoms in the unit cell.

CHAPTER

2

Dielectric Properties of Materials

When classifying solids on the basis of their band structure, we referred to the group of solids, called insulators, which have an energy gap of 3 eV or more. Electrical insulators have very few electrons to take part in normal conductivity. Such materials have interesting electrical properties because the applied electric field creates electric dipoles and the material becomes polarized. Materials in which polarization effects are important are called **dielectrics.** In another words we can say that the insulating materials used for storage of charge are known as **dielectric materials.**

2.1 DIELECTRIC

A dielectric is a non conducting material which can be polarized by an electric field. If the main function of non-conducting material is to provide electrical insulation, then material is called insulator. If the main function of non-conducting material is to provide storage of charge material is called dielectric.

2.1.1 Dielectric Parameters

There are four parameters to study the behaviour of dielectric materials as listed below:

- Dielectric constant ($\in_r$)
- Polarization (P)
- Dipole moment (p)
- Polarizability (α)

2.1.2 Dielectric Constant

Consider a parallel plate capacitor, with the area of the plates as a-meter^2 each, a distance d-meter apart in vacuum. The **capacitance** of this capacitor is

$$C_0 = \frac{\in_0 A}{d} \qquad \ldots(1)$$

$\in_0$ is dielectric constant or permittivity of vacuum and $\in_0 = 8.854 \times 10^{-12}$ Farad/meter.

If the space between the plates is filled with a dielectric material, the capacitance of the capacitor increases and is given by

$$C = \frac{\in_0 \in_r A}{d} \qquad \ldots(2)$$

- The alignment of the permanent dipoles with the electric field depends upon the shape of the solids and the interaction of the molecules.
- In **Solid Nitrobenzene ($C_6H_5NO_2$),** dipoles are frozen and so effect of orientation is negligible so, $\alpha_0 = 0$ and $P_0 = 0$.
- **Debye's generalization is applicable only for gases.**
- Piezoelectric materials can act as transducers because a mechanical strain induces an electric field and conversely, an electric field induces a mechanical strain or a dimensional change.
- Almost all **LCD devices** use **"nematic liquid crystals"**.
- **Piezoelectric crystals are also called "charge amplifier".**
- **In a transformer, the core material should have low coercivity and retentivity.**
- **Piezoelectricity is the reverse effect of "Electrostriction".**
- **Effective 'Q'** of the equivalent electrical circuit of **quartz crystal** is of the **order of 20,000.**
- **Lorentz-Lorentz equation** is applicable only for **electronic polarizability**.

OBJECTIVE BRAIN TEASERS

Q.1 Condition under which spontaneous polarization in a dielectric occurs is

(a) $\frac{N\alpha\gamma^2}{\epsilon_0} = 1$ (b) $\frac{N\alpha^2\gamma}{\epsilon_0} = 1$

(c) $\frac{N^2\alpha\gamma}{\epsilon_0} = 1$ (d) $\frac{N\alpha\gamma}{\epsilon_0} = 1$

Q.2 Ionic bonding in solid depends primarily on

(a) Vander Waal's forces

(b) Electrical dipole

(c) Sharing of electrons

(d) Transfer of electrons

Q.3 Consider the following statements:

1. Ionic polarisation is effective upto visible frequency range.
2. Electronic polarization is effective upto infrared frequency range.
3. Orientational polarisation is effective upto radio frequency range.

Which of the above statement/s is/are incorrect?

(a) 1 only (b) 1 and 2

(c) 2 and 3 (d) 1 and 3

Q.4 **Assertion (A):** Electronic polarization is independent of temperature.

Reason (R): It is found in materials having no interaction among the molecules.

Of these statements:

(a) Both A and R are true and R is the correct explanation of A.

(b) Both A and R are true but R is not a correct explanation of A.

(c) A is true but R is false.

(d) A is false but R is true.

Q.5 Consider the following statements:

The dielectric constant of an insulator depends on

1. applied voltage
2. frequency of the alternating field applied
3. temperature
4. maximum current density in insulator

Select the correct answer using the codes given below:

(a) 1 and 2 (b) 1 and 3

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

Q.6 Consider the following statements related to ferroelectric materials above the Curie temperature: