ESE 2017
UPSC ENGINEERING SERVICES EXAMINATION

Preliminary Examination

Paper I — **General Studies and Engineering Aptitude**

8

Basics of Material Science and Engineering

Comprehensive Theory *with* Practice Questions

As per new syllabus of ESE 2017

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ESE-2017 : Preliminary Examination
Paper-I : General Studies and Engineering Aptitude

Basics of Material Science and Engineering

1st Edition : 2016

Preface

B. Singh (Ex. IES)

The compilation of this book **Basics of Material Science and Engineering** was motivated by the desire to provide a concise book which can benefit students to understand the concepts of energy and environment topics.

This textbook **Basics of Material Science and Engineering** provides all the requirements of the students, i.e. comprehensive coverage of theory, fundamental concepts and objective type questions articulated in a lucid language. The concise presentation will help the readers grasp the theory of this subject with clarity and apply them with ease to solve objective questions quickly. This book not only covers the syllabus of ESE but also addresses the need of many other competitive examinations. Topics like 'Introduction, Chemical Bonding, Crystallography, Electronic Materials, Magnetic Properties of Materials, Ceramics, Polymers, Composites, Mechanical Properties of Materials, Ferrous Metals, Non-Ferrous Metals and Alloys' are given full emphasis, keeping in mind of our research on their importance in competitive examinations.

We have put in our sincere efforts to present detailed theory and MCQs without compromising the accuracy of answers. For the interest of the readers, some notes, do you know and interesting facts are given in the comprehensive manner. At the end of each chapter, sets of practice question are given with their keys, that will allow the readers to evaluate their understanding of the topics and sharper their question solving skills.

Our team has made their best efforts to remove all possible errors of any kind. Nonetheless, we would highly appreciate and acknowledge if you find and share with us any printing and conceptual errors.

It is impossible to thank all the individuals who helped us, but we would like to sincerely thank all the authors, editors and reviewers for putting in their efforts to publish this book.

With Best Wishes

B. Singh

CMD, MADE EASY

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Basic of Material Science & Engineering

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4.1 Introduction

- One of the principal characteristics of materials is their ability (or lack of ability) to conduct electrical current. Indeed, materials are classified by this property, i.e., they are divided into conductors, semiconductors and nonconductors (insulators or dielectrics). The conductivity, σ, of different materials at room-temperature spans more than 25 orders of magnitude. Moreover, when we take into consideration the conductivity of superconductors, measured at low temperatures, into consideration, this span extends to 40 orders of magnitude (taking an estimated conductivity for superconductors of about 10^{20} (Ω-cm)$^{-1}$. We may note that this is the largest known variation in a physical property and is comparable to the ratio between the diameter of the universe (~10^{26} m) and the radius of an electron (10^{-14} m).

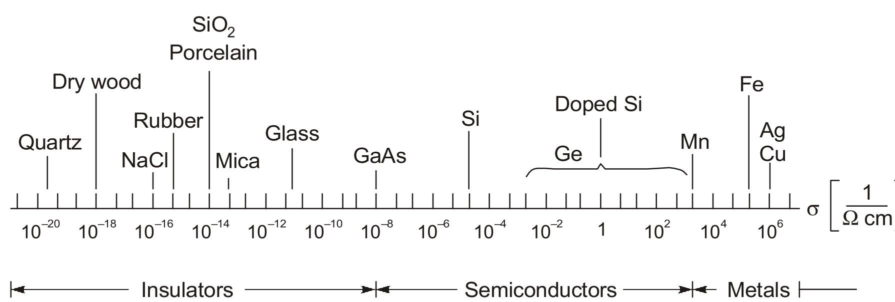
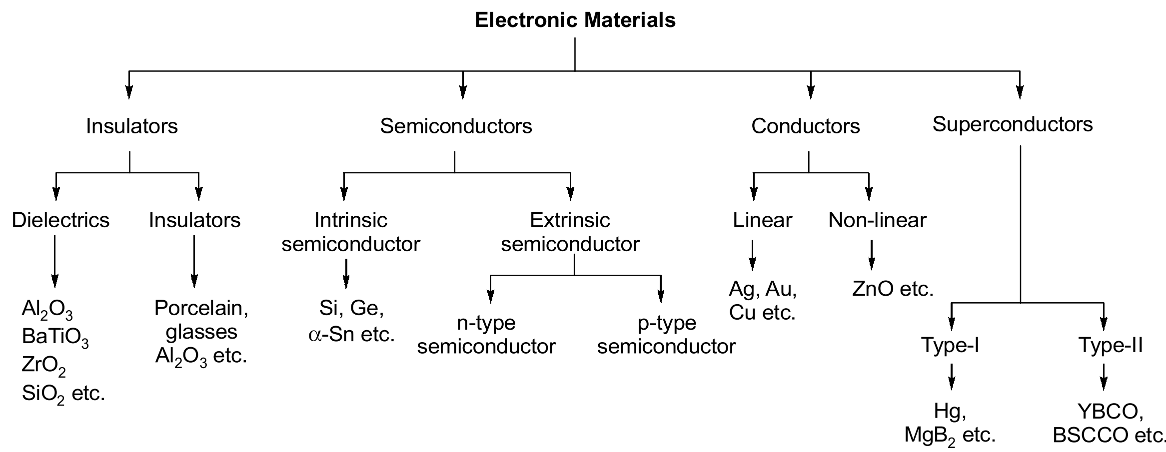


Fig. 4.1 *Room-temperature conductivity of various materials. (Superconductors, having conductivities of many orders of magnitude larger than copper, near 0 K, are not shown. The conductivity of semiconductors varies substantially with temperature and purity). The reciprocal of the ohm (Ω) is defined 1 siemens (S).*

- Electronic materials include insulators, semiconductors, conductors, and superconductors. This family of materials has revolutionized the entire world. From spark plugs made from alumina and copper wires for transmission of electric power to components for wireless communications, high power magnets used in Magnetic Resonance Imaging (MRI), capacitors, insulators, solar cells, active matrix displays, silicon and gallium arsenide based computer chips, electronic materials are found in numerous applications.
- Recent advances in materials have led to several breakthroughs in the development of new electronic materials. We now have ceramics that are not just excellent insulators, but also semiconductors and superconductors. Similarly, we have polymers which exhibit semiconducting and also superconducting properties. A simple and broad classification of some of the electronic materials is shown below.



4.2 Ohm's Law and Electrical Conductivity

- Ohm's law relates the current I (Ampere, A) or time rate of charge passage to the applied voltage V (Volt, V) as follows:

$$V = IR$$

where R is the resistance (Ohm, Ω)

- The units for V, I and R are respectively, volts (J/C), amperes (C/s), and Ohms (V/A).
- This law is applicable to most but not all materials.
- The value of R is influenced by specimen configuration and for several materials is independent of current. The resistance (R) of a resistor is a characteristics of the size, shape and properties of the materials used and expressed as

$$R = \frac{\rho l}{A} = \frac{l}{\sigma A}$$

where,

'l' is the length (m) of the resistor i.e., the distance between the two points at which the voltage is measured.

'A' is the cross-sectional area (m^2) perpendicular to the direction of current.

'ρ' is the electrical resistivity (Ω-m)

'σ' which is the reciprocal of 'ρ', is the electrical conductivity [$(\Omega\text{-m})^{-1}$].

Note: The magnitude of resistance depends upon the dimensions of resistor, as well as microstructure and composition of the material.

- The electrical conductivity (σ) is used to specify the electrical character of a material. It is reciprocal of the resistivity, i.e.,

$$\sigma = \frac{1}{\rho}$$

- Thus resistivity or conductivity allows one to compare different materials. Resistivity is a microstructure sensitive property.
- In addition to Ohm's law may be expressed as

$$J = \sigma E$$

where,
'J' (A/m^2) is the current density (I/A) i.e., the current per unit area of specimen.
'E' is the electric field intensity or the voltage difference between the two points divided by the distance (l) separating them, i.e.,

$$E = \frac{V}{l}$$

- One can also determine the current density (J) as

$$J = nq\bar{v}$$

where
'n' is number of charge carriers (carriers/m^3)
'q' is the charge on each carrier (1.6×10^{-19}C)
$\bar{v}$ is the average drift velocity (m/s) at which charge carriers move.

- Thus, we have

$$\sigma E = nq\bar{v}$$

or $$\sigma = nq\frac{\bar{v}}{E}$$

- The term $\frac{\bar{v}}{E}$ is the **mobility** of carriers and denoted by μ (m^2/V-sec). In the case of metals μ is the mobility of electrons.

- We have, $$\mu = \frac{\bar{v}}{E}$$

Thus, we have $$\boldsymbol{\sigma = nq\mu}$$ Here q is the charge.

Remember

- The electrical conductivity of materials can be controlled by
  (i) Controlling the number of charge carries in the materials.
  (ii) Controlling the mobility or ease of movement of the charge carriers.
- We may note that the mobility is particularly important in metals, whereas the number of carriers is more important in semiconductors and insulators.

- Charge carriers in metals are electrons, whereas charge carriers in semiconductors are both electrons and holes. Expression for conductivity gets modified for semiconductor as below.

$$\boldsymbol{\sigma = nq\mu_n + pq\mu_p}$$

where μ_n and μ_p are the mobilities of electrons and holes respectively. The terms n and p represents the concentrations of free electrons and holes in a semiconductor.

- Electrical conductivity of materials varies tremendously (Table 4.1).

Table 4.1 *Electrical conductivity of materials*

Material	Conductivity (ohm^{-1}, cm^{-1})	Material	Conductivity (ohm^{-1}, cm^{-1})
Superconductors		**Semiconductors**	
Hg, Nb_3Sn,	Infinite (under certain conditions such as low temperatures)	Group 4B elements	
$YBa_2Cu_3O_{7-x}$		Si	5×10^{-6}
		Ge	0.02
MgB_2		α-Sn	0.9×10^5