ESE-2022
Prelims Paper-I

Basics of
Material Science
and
Engineering

IES MASTER PUBLICATION

Office : F-126, (Lower Basement), Katwaria Sarai, New Delhi-110016 • **Phone :** 011-26522064
Mobile : 8130909220, 9711853908 • **E-mail:** info.publications@iesmaster.org, info@iesmaster.org
Web : iesmasterpublications.com, iesmaster.org

IES MASTER PUBLICATION

F-126, (Lower Basement), Katwaria Sarai, New Delhi-110016

Phone : 011-26522064, **Mobile :** 8130909220, 9711853908

E-mail : info.publications@iesmaster.org

Web : iesmasterpublications.com

First Edition : 2016

Second Edition : 2017

Third Edition : 2018

Fourth Edition : 2019

Fifth Edition : 2020

Sixth Edition : 2021

Typeset at : IES Master Publication, New Delhi-110016

PREFACE

Materials are the spinal cord of technology. Material Science is the scientific study of materials and their properties for resulting engineering design and improvement. An engineer must have a sound understanding of the basic concepts of Material Science.

This understanding of materials enables the engineers to select the most appropriate materials and use them with greatest efficiency whilst causing minimum pollution in their extraction, refinement and manufacturing.

This book has been written after intensive study of the probable topics in Material Science from where questions are expected. Based on the pattern and trend of questions asked in UPSC examinations, all the necessary concepts and information have been compiled in a simple and lucid form.

This revised and updated edition (**6th edition**) is primarily aimed at explaining the basic concepts of Material Science for students preparing for ESE. The treatment of each chapter is such as to start from the fundamentals and build up to the level of ESE.

This book is divided into **12 chapters** plus **one Annexure**. The Annexure given at the end of this book serves as a ready reckoner, covering short and brief description of properties of various important materials in the periodic table and short notes on metallurgical extraction, for a hassle-free learning.

This book has many student-friendly features. Important points, which are vital from examination point of view, are highlighted in the chapters, and at the end of each chapter these are given under 'Points to be Remembered'. A good number of practice questions are provided at the end of every chapter. So, as a topic is finished, students test their understanding in the language asked in the UPSC exam. The spin given to the concepts, tests the ability of the students to derive the correct answer, which facilitates the students to acquire necessary confidence. Students may generally not require any additional study and may be reasonably confident that all the probable questions and topics are covered in this book. Apart from the foresaid, UPSC sample papers and questions asked in **ESE 2020-21** are discussed after the completion of relevant topics.

All care has been taken to make the understanding of this subject more clear and interesting. The credit goes to the entire IES Master team for its continuous support in bringing out this book. Hope this will suffice the need of students who are preparing for Engineering Services Examination. All comments and suggestions for further improvement of the book are welcome, and will be appreciated.

Bipin Thakur
IES Master Publication
New Delhi

CONTENTS

1 Atomic Structure and Radioactivity

1.1 INTRODUCTION

All substances contain matter which can exist in three states; solid, liquid or gas. The constituent particles are held in different ways in these states of matter and they exhibit their characteristic properties. Matter can also be classified into elements, compounds or mixtures. An element contains particles of only one type which may be atoms or molecules. The compounds are formed where atoms of two or more elements combine in a fixed ratio to each other. Mixtures occur widely and many of the substances present around us are mixtures.

This chapter consider several fundamental and important concept namely atomic structure and it's related theory, electron configuration, periodic table, types of bonds that hold together the atoms comprising a solid and finally radioactivity at the end.

1.2 ATOMIC MODEL

The concept of atom was given by early Greek philosophers. In Greek the word atom means indivisible. In 1804, Dalton put forward his atomic theory, thereafter in 1815. Prout found that atomic weights of most elements were simple multiple of atomic weight of hydrogen atom but with time this has been discarded because it was found that certain elements have fraction atomic weights. According to modern concept, an atom is composed of a nucleus which is surrounded by electrons.

1.2.1 Dalton's Atomic Theory

The **Dalton's atomic theory** states that atoms are building blocks of matter.

According to Dalton's atomic theory:

- Matter consists of indivisible atoms
- All the atoms of a given element have identical properties including identical mass. Atoms of different elements differ in mass.
- Compounds are formed when atoms of different elements combine in a fixed ratio.

Draw back

- It can explain the laws of chemical combination by weight but it fails to explain Gay-Lussac's law of gaseous volume.
- It makes no distinction between the ultimate particles of an element and the smallest particle of a compound, both of which are made of atoms.
- It assumes that atoms of same element are like and have same mass. But this is not true for isotopes (two or more atoms with same atomic number but different atomic mass called isotopes).

  Example: ${}^{12}_{6}C$, ${}^{13}_{6}C$, ${}^{14}_{6}C$ have atoms of different mass. ${}^{1}_{1}H$, ${}^{2}_{1}H$, ${}^{3}_{1}H$ have atoms of different masses).

1.2.2 Avogadro's Hypothesis

Before Avogardo, Berzelius was the first who have been talking about atom. ***As per Berzelius assumed "equal volumes of different gases under identical conditions of temperature and pressure contain the same number of atoms*** (The word atom was at that time used for both elements and compounds as molecule was not thought of)." As per this theory if 1 atom of H_2 combines with 1/2 atom of O_2. Then this ***process allows atom to be divisible. This is against Dalton's atomic theory. Hence, Berzelius hypothesis was discarded***. Failure led to assume that gases exist in polyatomic state and ultimate particles which can exist in the free state were defined as molecule. Avogadro's hypothesis is based on molecules:

"Equal volume of all gases under the same conditions of temperature and pressure contain the same number of molecule".

The conclusions withdrawn by this theory are as follows:

- The word molecule made the distinction between atoms and molecules.
- Molecules of hydrogen, chlorine, oxygen, nitrogen and fluorine are diatomic.
- Molecular weight = 2 × vapour density.
- One gram-molecular mass (molecular weight) has volume 22.4 L (22.4×10^{-3} m^3) at NTP (pressure = 1 atm and T = 273.15 K)

Example 1.1

Consider the following statements :

Statement (I) : Atoms can neither be created nor destroyed.

Statement (II) : Under similar conditions of temperature and pressure, equal volumes of gases do not contain an equal number of atoms. ***[ESE–2018]***

Choose the correct option :

(a) I and II are correct
(b) Only I is correct
(c) Only II is correct
(d) None of the statement is correct.

Ans. (b)

1.2.3 Thomson's Atomic Model

J.J. Thomson, proposed that an atom possesses a spherical shape (radius approximately 10^{-10}m) in which the positive charge is uniformly distributed. The electrons are embedded into it, in such a manner as to give the most stable electrostatic arrangement.

- Atom is a sphere filled with positively charged matter distributed uniformly with sufficient electrons embedded in it to balance positive charge, hence atom is electrically neutral.
- The electrons possess vibratory motion about their equilibrium position and cause emission of light.

Drawbacks of the Model

Thomson's model did not explained

(i) Scattering of α-particles incident on metal foil.
(ii) Emission of spectral lines by the atoms.

1.2.4 Rutherford's Atomic Model

Rutherford did his famous α-particle scattering experiment. On the basis of his observations, Rutherford proposed the nuclear model of atom. According to this:

(i) The positive charge and most of the mass of the atom were densely concentrated in extremely small region. This very small portion of the atom was called **nucleus** by Rutherford.
(ii) The nucleus is surrounded by electrons that move around the nucleus with a very high speed in circular paths called **orbits**.

(iii) Electrons and the nucleus are held together by electrostatic forces of attraction.

Drawbacks of Rutherford's Atomic Model

A revolving electron must be continuously accelerating due to change in direction of motion. According to electromagnetic theory, an accelerating charge particle possesses centripetal acceleration and there would be continuous loss in energy of the revolving electron. Thus, the electron must move along a spiral path of decreasing radius and ultimately fall into the nucleus.

- Revolving electron must radiate continuous radiations of all increasing frequencies. But it is observed that elements emits lines of fixed frequencies.
- There is no discussion on distribution of electrons.

1.2.5 Atomic Spectra of Hydrogen and Bohr's Theory

When atoms are heated or subjected to an electric discharge, they absorb energy which is subsequently emitted as radiation. Atomic spectroscopy is an important technique for studying the energy and the arrangement of electrons in atoms.

If a discharge is passed through hydrogen gas (H_2) at a lower pressure, some hydrogen atoms (H) are formed, which emit light in the visible region. This light can be studied with a spectrometer, and is found to comprise a series of lines of different wavelengths.

Spectral Series Found in Atomic Hydrogen

1. Lyman series : Ultraviolet (n = 1)
2. Balmer series: Visible/ultraviolet (n = 2)
3. Paschen series: Infrared (n = 3)
4. Brackett series: Infrared (n = 4)
5. Pfund series: Infrared (n = 5)
6. Humphreys series: Infrared (n = 6)

   n = Principal quantum number which is described in later section.

Bohr's extended the above model further by applying Planck's quantum theory.

Assumptions of Bohr Theory

Bohr made the following assumptions in his theory:

(i) An atom consists of a nucleus in which whole of the mass and positive charge is concentrated. The electrons revolves around the nucleus in close circular orbit. The centripetal force required for rotation is provided by electrostatic force of attraction between nucleus and electrons.

Hence, $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r^2}$

where, m is the mass of electron revolving around the nucleus, Z is atomic number, e is charge on electron, v is orbital velocity of electron and $\in_0$ (= 8.854×10^{-12} F/m) is the permittivity of free space.

- Energy of electron revolving around the nucleus is given by

$$E = \frac{Z^2e^4m}{8\varepsilon_0^2n^2h^2}$$

where m = mass of electron, Z = atomic number, n = number of orbit, h is plank constant. Further, it is simplified in following way:

$$E = -\frac{2\pi^2me^4}{n^2h^2} = -\frac{13.6\ eV}{n^2}$$

(ii) The electron revolve only in certain non radiating orbits called as **stationary orbits**. There is no loss of energy in these orbits when electrons revolve. Bohr found that electron can only occupy an orbit for which the angular momentum of moving electron is an integral multiple of $h/2\pi$, where h is **Planck's constant**.

The use of reduced mass (inclusion of mass of nucleus) in kinetic energy explains why different isotopes of an element produce lines in the spectrum at slightly different wavelength (Reason for spectral series).

The orbits are denoted by the letters K, L, M, N … counting outwards from the nucleus and they are also numbered 1, 2, 3, 4 … This number is called the **principal quantum number**, which is given the symbol **'n'**.

(iii) When an electron jumps from an orbit of higher energy to another orbit of lower energy then energy is released in the form of radiations and vice-versa. The amount of energy released or