Atomic and Nuclear Physics

[For B.Sc. Classes as per UGC Model Syllabus]

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PREFACE TO THE REVISED EDITION

The present edition of the book is revised as per the UGC syllabus. Questions and problems at the end of each chapter have been up-dated. Many new solved examples are included in this edition.

Certain topics have been added so that students from some universities where the syllabus has been modified and upgraded may benefit.

Besides being a text-book we hope that this will benefit students appearing at the IAS, AMIE and other Competitive Examinations.

We are grateful to the students and teachers who have appreciated the book. Suggestions for further improvement of the book will be highly appreciated. Our grateful thanks are due to the staff of S. Chand and Co. Ltd, Shri Navin Joshi VP (Publishing), Shri Bhagirath Kaushik, General Manager for getting the book printed in-time and Shri D.R. Parab, Branch Manager for the co-ordination work.
UGC MODEL SYLLABUS (Course 7)
[Relativity, Quantum Mechanics, Atomic, Molecular and Nuclear Physics]

1. Relativity (15)
   Reference systems, inertial frames, Galilean invariance and conservation laws, propagation of
   light, Michelson-Morley experiment; search for ether. (5)

   Postulates for the special theory of relativity, Lorentz transformations, length contraction, time
dilation, velocity addition theorem, variation of mass with velocity, mass-energy equivalence, particle
with a zero rest mass, (10)

2. Quantum Mechanics (30)
   Origin of the quantum theory: Failure of classical physics to explain the phenomena such as
black-body spectrum, photoelectric effect, Ritz combination principle in spectra, stability of an atom.
Planck’s radiation law, Einstein’s explanation of photoelectric effect, Bohr’s quantization of angular
momentum and its applications to hydrogen atom, limitations of Bohr’s theory (5)

   Wave-particle duality and uncertainty principle: de Broglie’s hypothesis for matter waves, the
concept of wave and group velocities, evidence for diffraction and interference of particles’, experi-
mental demonstration of matter waves.

   Consequence of de Broglie’s concepts; quantisation in hydrogen atom; energies of a particle in
a box, wave packets, Heisenberg’s uncertainty relation for p and x, its extension to energy and time.

   Consequence of the uncertainty relation; gamma ray microscope, diffraction at a slit, particle in
a box, position of electron in a Bohar orbit.

   Quantum Mechanics: Schrödinger’s equation. postulatory basis of quantum mechanics: operators,
expectation values, transition probabilities, applications to particle in a one-and three-
dimensional boxes, harmonic oscillator, reflection at a step potential, transmission across a potential
barrier.

   Hydrogen atom: natural occurrence of n, l and m quantum numbers, the related physical quan-
ties, comparison with Bohr’s theory.

3. Atomic Physics (15)
   Spectra of hydrogen, deuteron and alkali atoms spectral terms, doublet fine structure, screening
constants for alkali spectra for s, p, d, and f states, selection rules. (6)

   Singlet and triplet fine structure in alkaline earth spectra, L-S and J-J couplings. (3)

   Week spectra: continuous X-ray spectrum and its dependence on voltage, Duane and Hunt’s,

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   Discrete set of electronic energies of molecules, quantisation of vibrational and rotational ener-
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vibration spectra.

   Raman effect, Stokes and anti-Stokes lines, complimentary character of Raman and infrared
spectra, experimental arrangements for Raman spectroscopy. (3)
Spectroscopic techniques: Sources of excitation, prism and grating spectrographs for visible, UV and IR, absorption spectroscopy, double beam instruments, different recording systems. (5)

5. Nuclear Physics (15)

Interaction of charged particles and neutrons with matter, working of nuclear detectors, G-M counter, proportional counter and scintillation counter, cloud chambers, spark chamber, emulsions. (5)

Structure of nuclei, basic properties (I, l, Q and binding energy), deuteron binding energy, p-p and n-p scattering and general concepts of nuclear forces. Beta decay, range of alpha particle Geiger-Nuttal law. Gamow’s explanation of beta decay, alpha decay and continuous and discrete spectra. (5)

Nuclear reactions, channels, compound nucleus, direct reaction (concepts) (3)

Shell model; liquid drop model, fission and fusion (concepts), energy production in stars by pop and carbon cycles (concepts). (2)
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1

SPECIAL THEORY OF RELATIVITY

1.1 Frame of Reference

Rest and motion are relative terms. To define motion, the observer must define a frame of reference relative to which the motion is considered.

A body in motion can be located with reference to some coordinate system called the frame of reference. If the co-ordinates of all the points of a body remain unchanged with time and with respect to the frame of reference, the body is said to be at rest. If, however, the co-ordinates of any point of the body change with time and with respect to the frame of reference, the body is said to be in motion.

Suppose a body \( P \) is at the point \( A \). Its co-ordinates are \((x, y, z)\) with respect to the frame of reference (Fig. 1.1). If the body \( P \) always remains at \( A \), it will be at rest with respect to the frame of reference. If another body \( Q \) is initially at \( A \) and after some time it is at \( B (x_1, y_1, z_1) \), it is in motion with respect to the frame of reference.

Now consider two frames of reference \( X'Y'Z' \) and \( \bar{X}Y'Z' \) (Fig. 1.2).

The observer \( O \) considers the motion of \( P \) with respect to the frame of reference \( XYZ \) and the observer \( O' \) with respect to the frame of reference \( X'Y'Z' \).

If \( O \) and \( O' \) are at rest with respect to each other, they will observe the same motion of \( P \). If \( O \) and \( O' \) are in relative motion, their observation of motion will be different.

Examples

1. Consider two observers \( A \) and \( B \). \( A \) is on the earth and \( B \) is on the sun. Both observe the motion of the moon. To the observer \( A \), moon will appear to move along a circular path.
To the observer $B$, moon will appear to move in a wavy path.

2. Consider a car in motion. To an observer at the centre of wheel any point on the rim will appear to move along a circular path. But, to an observer on the ground the path of the point on the rim will appear to be a cycloid (Fig. 1.3).

![Fig. 1.3.](image_url)

3. Consider that a train is moving with uniform velocity. A person sitting in the train drops a stone from the window. To this person the stone will appear to be falling vertically downwards. But, to a person standing near the track, the stone will appear to move along a parabolic path.

4. Consider a person $A$ sitting in a train. All the windows of the train are closed and the person $A$ cannot see anything outside. If the train is moving with uniform velocity, a stone thrown upward will return to the thrower. It means that this person cannot find the velocity of the train $i.e.$, the frame in which he is located. On the other hand, if the train is accelerated the stone thrown upward will not return to the thrower. This is the case of a non-inertial of reference.

1.2 Inertial Frames

We locate objects in space using a co-ordinate system. This co-ordinate system is referred to as reference frame or a frame of reference.

There are two types of reference frames:

(i) Inertial frame

(ii) Non-inertial or accelerated frame.

An inertial system is defined as a frame of reference in which the law of inertia holds $i.e.$, Newton’s first law holds. Such a system is an unaccelerated system $i.e.$, it moves with a constant velocity (or is at rest).

Frames of reference which are accelerating with respect to some other frame are not inertial. In this frame the law of inertia is not valid.

It is convenient to take a fixed star (pole) as a standard inertial frame of reference. For practical purpose, the earth can be taken as an inertial frame of reference. Its rotation around its own axis can be taken to be negligibly small. In fact, it depends on the experiment to be performed whether earth can be taken as an inertial frame of reference or not.

1.3 Galilean Transformation Equations

Let an inertial frame $S'$ move with a constant velocity $\vec{v}$ with respect to an inertial frame $S$. So that the relative motion is along the common $X - X'$ axis. At time $t = O$, the two origins $O$ and $O'$ coincide. Consider an event to occur at some point $P$, whose space and time co-ordinates are measured in each inertial frame. The event is given by the co-ordinates $x, y, z$ and time $t$ to an observer in the $S$-frame and by $x', y', z'$ and $t'$ to an observer attached to the $S'$ frame.

To find the Galilean transformation equations $i.e.$, equations that relate the two co-ordinates $x, y, z, t$ and $x', y', z', t'$. According to classical theory motion does not affect the lengths