

PHYSICS

PART I

TEXTBOOK FOR CLASS XI



11086

विद्यया ऽ मृतमश्नुते



एन सी ई आर टी
NCERT

राष्ट्रीय शैक्षिक अनुसंधान और प्रशिक्षण परिषद्
NATIONAL COUNCIL OF EDUCATIONAL RESEARCH AND TRAINING

ISBN 81-7450-508-3

First Edition

February 2006 Phalgun 1927

Reprinted

October 2006 Kartika 1928
 December 2007 Pausa 1929
 January 2009 Pausa 1930
 January 2010 Pausa 1931
 January 2011 Pausa 1932
 March 2012 Phalgun 1933
 November 2012 Kartika 1934
 November 2013 Kartika 1935
 December 2014 Pausa 1936
 May 2016 Vaishakha 1938
 February 2017 Phalgun 1938
 December 2017 Pausa 1939
 January 2019 Magha 1940
 October 2019 Ashvina 1941

PD 450T BS

© **National Council of Educational
 Research and Training, 2006**

₹ 150.00

Printed on 80 GSM paper with NCERT
 watermark

Published at the Publication Division by the
 Secretary, National Council of Educational
 Research and Training, Sri Aurobindo Marg,
 New Delhi 110016 and printed at
 Kalyan Enterprises, D-20, Sector B-3,
 Tronica City Industrial Area, Loni,
 Ghaziabad - 201 102 (U.P.)

ALL RIGHTS RESERVED

- ❑ No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without the prior permission of the publisher.
- ❑ This book is sold subject to the condition that it shall not, by way of trade, be lent, re-sold, hired out or otherwise disposed of without the publisher's consent, in any form of binding or cover other than that in which it is published.
- ❑ The correct price of this publication is the price printed on this page. Any revised price indicated by a rubber stamp or by a sticker or by any other means is incorrect and should be unacceptable.

**OFFICES OF THE PUBLICATION
 DIVISION, NCERT**

NCERT Campus
 Sri Aurobindo Marg
 New Delhi 110 016

Phone : 011-26562708

108, 100 Feet Road
 Hosdakere Halli Extension
 Banashankari III Stage
 Bengaluru 560 085

Phone : 080-26725740

Navjivan Trust Building
 P.O. Navjivan
 Ahmedabad 380 014

Phone : 079-27541446

CWC Campus
 Opp. Dhankal Bus Stop
 Panihati
 Kolkata 700 114

Phone : 033-25530454

CWC Complex
 Maligaon
 Guwahati 781 021

Phone : 0361-2674869

Publication Team

Head, Publication Division : *Anup Kumar Rajput*
 Chief Editor : *Shveta Uppal*
 Chief Production Officer : *Arun Chitkara*
 Chief Business Manager : *Bibash Kumar Das*
 Assistant Editor : *R.N. Bhardwaj*
 Production Assistant : *Prakash Veer Singh*

Cover and Illustrations
Shweta Rao

FOREWORD

The National Curriculum Framework (NCF), 2005 recommends that children's life at school must be linked to their life outside the school. This principle marks a departure from the legacy of bookish learning which continues to shape our system and causes a gap between the school, home and community. The syllabi and textbooks developed on the basis of NCF signify an attempt to implement this basic idea. They also attempt to discourage rote learning and the maintenance of sharp boundaries between different subject areas. We hope these measures will take us significantly further in the direction of a child-centred system of education outlined in the National Policy on Education (1986).

The success of this effort depends on the steps that school principals and teachers will take to encourage children to reflect on their own learning and to pursue imaginative activities and questions. We must recognise that, given space, time and freedom, children generate new knowledge by engaging with the information passed on to them by adults. Treating the prescribed textbook as the sole basis of examination is one of the key reasons why other resources and sites of learning are ignored. Inculcating creativity and initiative is possible if we perceive and treat children as participants in learning, not as receivers of a fixed body of knowledge.

These aims imply considerable change in school routines and mode of functioning. Flexibility in the daily time-table is as necessary as rigour in implementing the annual calendar so that the required number of teaching days are actually devoted to teaching. The methods used for teaching and evaluation will also determine how effective this textbook proves for making children's life at school a happy experience, rather than a source of stress or boredom. Syllabus designers have tried to address the problem of curricular burden by restructuring and reorienting knowledge at different stages with greater consideration for child psychology and the time available for teaching. The textbook attempts to enhance this endeavour by giving higher priority and space to opportunities for contemplation and wondering, discussion in small groups, and activities requiring hands-on experience.

The National Council of Educational Research and Training (NCERT) appreciates the hard work done by the textbook development committee responsible for this book. We wish to thank the Chairperson of the advisory group in science and mathematics, Professor J.V. Narlikar and the Chief Advisor for this book, Professor A.W. Joshi for guiding the work of this committee. Several teachers contributed to the development of this textbook; we are grateful to their principals for making this possible. We are indebted to the institutions and organisations which have generously permitted us to draw upon their resources, material and personnel. We are especially grateful to the members of the National Monitoring Committee, appointed by the Department of Secondary and Higher Education, Ministry of Human Resource Development under the Chairpersonship of Professor Mrinal Miri and Professor G.P. Deshpande, for their valuable time and contribution. As an organisation committed to systemic reform and continuous improvement in the quality of its products, NCERT welcomes comments and suggestions which will enable us to undertake further revision and refinement.

New Delhi
20 December 2005

Director
National Council of Educational
Research and Training

THE CONSTITUTION OF INDIA

PREAMBLE

WE, THE PEOPLE OF INDIA, having solemnly resolved to constitute India into a ¹**[SOVEREIGN SOCIALIST SECULAR DEMOCRATIC REPUBLIC]** and to secure to all its citizens :

JUSTICE, social, economic and political;

LIBERTY of thought, expression, belief, faith and worship;

EQUALITY of status and of opportunity; and to promote among them all

FRATERNITY assuring the dignity of the individual and the ²[unity and integrity of the Nation];

IN OUR CONSTITUENT ASSEMBLY this twenty-sixth day of November, 1949 do **HEREBY ADOPT, ENACT AND GIVE TO OURSELVES THIS CONSTITUTION.**

1. Subs. by the Constitution (Forty-second Amendment) Act, 1976, Sec.2, for "Sovereign Democratic Republic" (w.e.f. 3.1.1977)
2. Subs. by the Constitution (Forty-second Amendment) Act, 1976, Sec.2, for "Unity of the Nation" (w.e.f. 3.1.1977)

TEXTBOOK DEVELOPMENT COMMITTEE

CHAIRPERSON, ADVISORY GROUP FOR TEXTBOOKS IN SCIENCE AND MATHEMATICS

J.V. Narlikar, *Emeritus Professor*, Chairman, Advisory Committee, Inter University Centre for Astronomy and Astrophysics (IUCAA), Ganeshkhind, Pune University, Pune

CHIEF ADVISOR

A.W. Joshi, *Professor*, Honorary Visiting Scientist, NCRA, Pune (Formerly at Department of Physics, University of Pune)

MEMBERS

Anuradha Mathur, *PGT*, Modern School, Vasant Vihar, New Delhi

Chitra Goel, *PGT*, Rajkiya Pratibha Vikas Vidyalaya, Tyagraj Nagar, Lodhi Road, New Delhi

Gagan Gupta, *Reader*, DESM, NCERT, New Delhi

H.C. Pradhan, *Professor*, Homi Bhabha Centre of Science Education, Tata Institute of Fundamental Research, V.N. Purav Marg, Mankhurd, Mumbai

N. Panchapakesan, *Professor (Retd.)*, Department of Physics and Astrophysics, University of Delhi, Delhi

P.K. Srivastava, *Professor (Retd.)*, Director, CSEC, University of Delhi, Delhi

P.K. Mohanty, *PGT*, Sainik School, Bhubaneswar

P.C. Agarwal, *Reader*, Regional Institute of Education, NCERT, Sachivalaya Marg, Bhubaneswar

R. Joshi, *Lecturer (S.G.)*, DESM, NCERT, New Delhi

S. Rai Choudhary, *Professor*, Department of Physics and Astrophysics, University of Delhi, Delhi

S.K. Dash, *Reader*, DESM, NCERT, New Delhi

Sher Singh, *PGT*, NDMC Navyug School, Lodhi Road, New Delhi

S.N. Prabhakara, *PGT*, DM School, Regional Institute of Education, NCERT, Mysore

Thiyam Jekendra Singh, *Professor*, Department of Physics, University of Manipur, Imphal

V.P. Srivastava, *Reader*, DESM, NCERT, New Delhi

MEMBER-COORDINATOR

B.K. Sharma, *Professor*, DESM, NCERT, New Delhi

ACKNOWLEDGEMENTS

The National Council of Educational Research and Training acknowledges the valuable contribution of the individuals and organisations involved in the development of Physics textbook for Class XI. The Council also acknowledges the valuable contribution of the following academics for reviewing and refining the manuscripts of this book: Deepak Kumar, *Professor*, School of Physical Sciences, Jawaharlal Nehru University, New Delhi; Pankaj Sharan, *Professor*, Jamia Millia Islamia, New Delhi; Ajoy Ghatak, *Emeritus Professor*, Indian Institute of Technology, New Delhi; V. Sundara Raja, *Professor*, Sri Venkateswara University, Tirupati, Andhra Pradesh; C.S. Adgaonkar, *Reader (Retd)*, Institute of Science, Nagpur, Maharashtra; D.A. Desai, *Lecturer (Retd)*, Ruparel College, Mumbai, Maharashtra; F.I. Surve, *Lecturer*, Nowrosjee Wadia College, Pune, Maharashtra; Atul Mody, *Lecturer (SG)*, VES College of Arts, Science and Commerce, Chembur, Mumbai, Maharashtra; A.K. Das, *PGT*, St. Xavier's Senior Secondary School, Delhi; Suresh Kumar, *PGT*, Delhi Public School, Dwarka, New Delhi; Yashu Kumar, *PGT*, Kulachi Hansraj Model School, Ashok Vihar, Delhi; K.S. Upadhyay, *PGT*, Jawahar Navodaya Vidyalaya, Muzaffar Nagar (U.P.); I.K. Gogia, *PGT*, Kendriya Vidyalaya, Gole Market, New Delhi; Vijay Sharma, *PGT*, Vasant Valley School, Vasant Kunj, New Delhi; R.S. Dass, *Vice Principal (Retd)*, Balwant Ray Mehta Vidya Bhawan, Lajpat Nagar, New Delhi and Parthasarathi Panigrahi, *PGT*, D.V. CLW Girls School, Chittranjan, West Bengal.

The Council also gratefully acknowledges the valuable contribution of the following academics for the editing and finalisation of this book: A.S. Mahajan, *Professor (Retd)*, Indian Institute of Technology, Mumbai, Maharashtra; D.A. Desai, *Lecturer (Retd)*, Ruparel College, Mumbai, Maharashtra; V.H. Raybagkar, *Reader*, Nowrosjee Wadia College, Pune, Maharashtra and Atul Mody, *Lecturer (SG)*, VES College of Arts, Science and Commerce, Chembur, Mumbai, Maharashtra.

The council also acknowledges the valuable contributions of the following academics for reviewing and refining the text in 2017: A.K. Srivastava, DESM, NCERT, New Delhi; Arnab Sen, NERIE, New Delhi; L.S. Chauhan, RIE, Bhopal; O.N. Awasthi (*Retd.*), RIE., Bhopal; Rachna Garg, DESM, NCERT, New Delhi; Raman Namboodiri, RIE, Mysuru; R.R. Koireng, DCS, NCERT, New Delhi; Shashi Prabha, DESM, NCERT, New Delhi; and S.V. Sharma, RIE, Ajmer.

Special thanks are due to M. Chandra, *Professor and Head*, DESM, NCERT for her support.

The Council also acknowledges the efforts of Deepak Kapoor, *Incharge*, Computer Station, Inder Kumar, *DTP Operator*; Saswati Banerjee, *Copy Editor*; Abhimanu Mohanty and Anuradha, *Proof Readers* in shaping this book.

The contributions of the Publication Department in bringing out this book are also duly acknowledged.

PREFACE

More than a decade ago, based on National Policy of Education (NPE-1986), National Council of Educational Research and Training published physics textbooks for Classes XI and XII, prepared under the chairmanship of Professor T. V. Ramakrishnan, F.R.S., with the help of a team of learned co-authors. The books were well received by the teachers and students alike. The books, in fact, proved to be milestones and trend-setters. However, the development of textbooks, particularly science books, is a dynamic process in view of the changing perceptions, needs, feedback and the experiences of the students, educators and the society. Another version of the physics books, which was the result of the revised syllabus based on *National Curriculum Framework for School Education-2000* (NCFSE-2000), was brought out under the guidance of Professor Suresh Chandra, which continued up to now. Recently the NCERT brought out the *National Curriculum Framework-2005* (NCF-2005), and the syllabus was accordingly revised during a curriculum renewal process at school level. The higher secondary stage syllabus (NCERT, 2005) has been developed accordingly. The Class XI textbook contains fifteen chapters in two parts. Part I contains first eight chapters while Part II contains next seven chapters. This book is the result of the renewed efforts of the present Textbook Development Team with the hope that the students will appreciate the beauty and logic of physics. The students may or may not continue to study physics beyond the higher secondary stage, but we feel that they will find the thought process of physics useful in any other branch they may like to pursue, be it finance, administration, social sciences, environment, engineering, technology, biology or medicine. For those who pursue physics beyond this stage, the matter developed in these books will certainly provide a sound base.

Physics is basic to the understanding of almost all the branches of science and technology. It is interesting to note that the ideas and concepts of physics are increasingly being used in other branches such as economics and commerce, and behavioural sciences too. We are conscious of the fact that some of the underlying simple basic physics principles are often conceptually quite intricate. In this book, we have tried to bring in a conceptual coherence. The pedagogy and the use of easily understandable language are at the core of our effort without sacrificing the **rigour** of the subject. The nature of the subject of physics is such that a certain minimum use of mathematics is a must. We have tried to develop the mathematical formulations in a logical fashion, as far as possible.

Students and teachers of physics must realise that physics is a branch which needs to be understood, not necessarily memorised. As one goes from secondary to higher secondary stage and beyond, physics involves mainly four components, (a) large amount of **mathematical base**, (b) **technical words and terms**, whose normal English meanings could be quite different, (c) new **intricate concepts**, and (d) **experimental foundation**. Physics needs mathematics because we wish to develop objective description of the world around us and express our observations in terms of measurable quantities. Physics discovers new properties of particles and wants to create a name for each one. The words are picked up normally from common English or Latin or Greek, but gives entirely different meanings to these words. It would be illuminating to look up words like energy, force, power, charge, spin, and several others, in any standard English dictionary, and compare their

meanings with their physics meanings. Physics develops intricate and often weird-looking concepts to explain the behaviour of particles. Finally, it must be remembered that entire physics is based on observations and experiments, without which a theory does not get acceptance into the domain of physics.

This book has some features which, we earnestly hope, will enhance its usefulness for the students. Each chapter is provided with a **Summary** at its end for a quick overview of the contents of the chapter. This is followed by **Points to Ponder** which points out the likely misconceptions arising in the minds of students, hidden implications of certain statements/principles given in the chapter and **cautions** needed in applying the knowledge gained from the chapter. They also raise some thought-provoking questions which would make a student think about life beyond physics. Students will find it interesting to think and apply their mind on these **points**. Further, a large number of **solved examples** are included in the text in order to clarify the concepts and/or to illustrate the application of these concepts in everyday real-life situations. Occasionally, historical perspective has been included to share the excitement of sequential development of the subject of physics. Some **Boxed** items are introduced in many chapters either for this purpose or to highlight some special features of the contents requiring additional attention of the learners. Finally, a **Subject Index** has been added at the end of the book for ease in locating keywords in the book.

The special nature of physics demands, apart from conceptual understanding, the knowledge of certain conventions, basic mathematical tools, numerical values of important physical constants, and systems of measurement units covering a vast range from microscopic to galactic levels. In order to equip the students, we have included the necessary tools and database in the form of **Appendices A-1 to A-9** at the end of the book. There are also some other appendices at the end of some chapters giving additional information or applications of matter discussed in that chapter.

Special attention has been paid for providing illustrative figures. To increase the clarity, the figures are drawn in two colours. A large number of **Exercises** are given at the end of each chapter. Some of these are from real-life situations. Students are urged to solve these and in doing so, they may find them very educative. Moreover, some **Additional Exercises** are given which are more challenging. Answers and hints to solve some of these are also included. In the entire book, SI units have been used. A comprehensive account of 'units and measurement' is given in Chapter 2 as a part of prescribed syllabus/curriculum as well as a help in their pursuit of physics. A box-item in this chapter brings out the difficulty in measuring as simple a thing as the length of a long curved line. Tables of SI base units and other related units are given here merely to indicate the presently accepted definitions and to indicate the high degree of accuracy with which measurements are possible today. The numbers given here are not to be memorised or asked in examinations.

There is a perception among students, teachers, as well as the general public that there is a steep gradient between secondary and higher secondary stages. But a little thought shows that it is bound to be there in the present scenario of education. Education up to secondary stage is general education where a student has to learn several subjects – sciences, social sciences, mathematics, languages, at an elementary level. Education at the higher secondary stage and beyond, borders on acquiring professional competence, in some chosen fields of endeavour. You may like to compare this with the following situation. Children play cricket or badminton in lanes and small spaces outside (or inside) their homes. But then

some of them want to make it to the school team, then district team, then State team and then the National team. At every stage, there is bound to be a steep gradient. Hard work would have to be put in whether students want to pursue their education in the area of sciences, humanities, languages, music, fine arts, commerce, finance, architecture, or if they want to become sportspersons or fashion designers.

Completing this book has only been possible because of the spontaneous and continuous support of many people. The Textbook Development Team is thankful to Dr. V. H. Raybagkar for allowing us to use his box item in Chapter 4 and to Dr. F. I. Surve for allowing us to use two of his box items in Chapter 15. We express also our gratitude to the Director, NCERT, for entrusting us with the task of preparing this textbook as a part of national effort for improving science education. The Head, Department of Education in Science and Mathematics, NCERT, was always willing to help us in our endeavour in every possible way.

The previous text got excellent academic inputs from teachers, students and experts who sincerely suggested improvement during the past few years. We are thankful to all those who conveyed these inputs to NCERT. We are also thankful to the members of the Review Workshop and Editing Workshop organised to discuss and refine the first draft. We thank the Chairmen and their teams of authors for the text written by them in 1988, which provided the base and reference for developing the 2002 version as well as the present version of the textbook. Occasionally, substantial portions from the earlier versions, particularly those appreciated by students/teachers, have been adopted/adapted and retained in the present book for the benefit of coming generation of learners.

We welcome suggestions and comments from our valued users, especially students and teachers. We wish our young readers a happy journey to the exciting realm of physics.

A. W. JOSHI
Chief Advisor
Textbook Development Committee

A NOTE FOR THE TEACHERS

To make the curriculum learner-centred, students should be made to participate and interact in the learning process directly. Once a week or one out of every six classes would be a good periodicity for such seminars and mutual interaction. Some suggestions for making the discussion participatory are given below, with reference to some specific topics in this book.

Students may be divided into groups of five to six. The membership of these groups may be rotated during the year, if felt necessary.

The topic for discussion can be presented on the board or on slips of paper. Students should be asked to write their reactions or answers to questions, whichever is asked, on the given sheets. They should then discuss in their groups and add modifications or comments in those sheets. These should be discussed either in the same or in a different class. The sheets may also be evaluated.

We suggest here three possible topics from the book. The first two topics suggested are, in fact, very general and refer to the development of science over the past four centuries or more. Students and teachers may think of more such topics for each seminar.

1. Ideas that changed civilisation

Suppose human beings are becoming extinct. A message has to be left for future generations or alien visitors. Eminent physicist R P Feynmann wanted the following message left for future beings, if any.

“Matter is made up of atoms”

A lady student and teacher of literature, wanted the following message left:

“Water existed, so human beings could happen”.

Another person thought it should be: **“Idea of wheel for motion”**

Write down what message each one of you would like to leave for future generations. Then discuss it in your group and add or modify, if you want to change your mind. Give it to your teacher and join in any discussion that follows.

2. Reductionism

Kinetic Theory of Gases relates the Big to the Small, the Macro to the Micro. A gas as a system is related to its components, the molecules. This way of describing a system as a result of the properties of its components is usually called **Reductionism**. It explains the behaviour of the group by the simpler and predictable behaviour of individuals. Macroscopic observations and microscopic properties have a mutual interdependence in this approach. Is this method useful?

This way of understanding has its limitations outside physics and chemistry, may be even in these subjects. A painting **cannot** be discussed as a collection of the properties of chemicals used in making the canvas and the painting. What emerges is more than the sum of its components.

Question: Can you think of other areas where such an approach is used?

Describe briefly a system which is fully describable in terms of its components. Describe one which is not. Discuss with other members of the group and write your views. Give it to your teacher and join in any discussion that may follow.

3. Molecular approach to heat

Describe what you think will happen in the following case. An enclosure is separated by a porous wall into two parts. One is filled with nitrogen gas (N_2) and the other with CO_2 . Gases will diffuse from one side to the other.

Question 1: Will both gases diffuse to the same extent? If not, which will diffuse more. Give reasons.

Question 2: Will the pressure and temperature be unchanged? If not, what will be the changes in both. Give reasons.

Write down your answers. Discuss with the group and modify them or add comments. Give to the teacher and join in the discussion.

Students and teachers will find that such seminars and discussions lead to tremendous understanding, not only of physics, but also of science and social sciences. They also bring in some maturity among students.

CONTENTS

FOREWORD	<i>iii</i>
PREFACE	<i>v</i>
A NOTE FOR THE TEACHER	<i>x</i>

CHAPTER 1

PHYSICAL WORLD

1.1	What is physics ?	1
1.2	Scope and excitement of physics	2
1.3	Physics, technology and society	5
1.4	Fundamental forces in nature	6
1.5	Nature of physical laws	10

CHAPTER 2

UNITS AND MEASUREMENTS

2.1	Introduction	16
2.2	The international system of units	16
2.3	Measurement of length	18
2.4	Measurement of mass	21
2.5	Measurement of time	22
2.6	Accuracy, precision of instruments and errors in measurement	22
2.7	Significant figures	27
2.8	Dimensions of physical quantities	31
2.9	Dimensional formulae and dimensional equations	31
2.10	Dimensional analysis and its applications	32

CHAPTER 3

MOTION IN A STRAIGHT LINE

3.1	Introduction	39
3.2	Position, path length and displacement	39
3.3	Average velocity and average speed	42
3.4	Instantaneous velocity and speed	43
3.5	Acceleration	45
3.6	Kinematic equations for uniformly accelerated motion	47
3.7	Relative velocity	51

CHAPTER 4

MOTION IN A PLANE

4.1	Introduction	65
4.2	Scalars and vectors	65
4.3	Multiplication of vectors by real numbers	67
4.4	Addition and subtraction of vectors – graphical method	67
4.5	Resolution of vectors	69

4.6	Vector addition – analytical method	71
4.7	Motion in a plane	72
4.8	Motion in a plane with constant acceleration	75
4.9	Relative velocity in two dimensions	76
4.10	Projectile motion	77
4.11	Uniform circular motion	79

CHAPTER 5

LAWS OF MOTION

5.1	Introduction	89
5.2	Aristotle's fallacy	90
5.3	The law of inertia	90
5.4	Newton's first law of motion	91
5.5	Newton's second law of motion	93
5.6	Newton's third law of motion	96
5.7	Conservation of momentum	98
5.8	Equilibrium of a particle	99
5.9	Common forces in mechanics	100
5.10	Circular motion	104
5.11	Solving problems in mechanics	105

CHAPTER 6

WORK, ENERGY AND POWER

6.1	Introduction	114
6.2	Notions of work and kinetic energy : The work-energy theorem	116
6.3	Work	116
6.4	Kinetic energy	117
6.5	Work done by a variable force	118
6.6	The work-energy theorem for a variable force	119
6.7	The concept of potential energy	120
6.8	The conservation of mechanical energy	121
6.9	The potential energy of a spring	123
6.10	Various forms of energy : the law of conservation of energy	126
6.11	Power	128
6.12	Collisions	129

CHAPTER 7

SYSTEM OF PARTICLES AND ROTATIONAL MOTION

7.1	Introduction	141
7.2	Centre of mass	144
7.3	Motion of centre of mass	148
7.4	Linear momentum of a system of particles	149
7.5	Vector product of two vectors	150
7.6	Angular velocity and its relation with linear velocity	152
7.7	Torque and angular momentum	154
7.8	Equilibrium of a rigid body	158
7.9	Moment of inertia	163
7.10	Theorems of perpendicular and parallel axes	164

7.11	Kinematics of rotational motion about a fixed axis	167
7.12	Dynamics of rotational motion about a fixed axis	169
7.13	Angular momentum in case of rotations about a fixed axis	171
7.14	Rolling motion	173

CHAPTER 8

GRAVITATION

8.1	Introduction	183
8.2	Kepler's laws	184
8.3	Universal law of gravitation	185
8.4	The gravitational constant	189
8.5	Acceleration due to gravity of the earth	189
8.6	Acceleration due to gravity below and above the surface of earth	190
8.7	Gravitational potential energy	191
8.8	Escape speed	193
8.9	Earth satellite	194
8.10	Energy of an orbiting satellite	195
8.11	Geostationary and polar satellites	196
8.12	Weightlessness	197

APPENDICES	207
------------	-----

ANSWERS	223
---------	-----

COVER DESIGN

(Adapted from the website of the Nobel Foundation
<http://www.nobelprize.org>)

The strong nuclear force binds protons and neutrons in a nucleus and is the strongest of nature's four fundamental forces. A mystery surrounding the strong nuclear force has been solved. The three quarks within the proton can sometimes appear to be free, although no free quarks have ever been observed. The quarks have a quantum mechanical property called 'colour' and interact with each other through the exchange of particles called 'gluons' — nature glue.

BACK COVER

(Adapted from the website of the ISRO
<http://www.isro.gov.in>)

CARTOSAT-1 is a state-of-the-art Remote Sensing Satellite, being eleventh one in the Indian Remote Sensing (IRS) Satellite Series, built by ISRO. CARTOSAT-1, having mass of 156 kg at lift off, has been launched into a 618 km high polar Sun Synchronous Orbit (SSO) by ISRO's Polar Satellite Launch Vehicle, PSLV-C6. It is mainly intended for cartographic applications.
