Introduction to Quantum Mechanics

Quantum mechanics is a subfield of physics that studies how the universe works at atomic and subatomic levels. It is an essential part of undergraduate and graduate courses in physics and undergraduate engineering courses in India.

This book comes from the desk of authors who have decades of graduate-level teaching experience in quantum mechanics. It covers the syllabus requirements set forth by the University Grants Commission (UGC), India, and has additional several unique features that will set it apart. It introduces the students to vector space in the beginning to give a comprehensive idea of the mathematics involved in the concepts, has separate appendices emphasizing the techniques of differential equations, and covers applications of quantum mechanics related to atomic physics, condensed matter physics, particle physics, and so on. The text is carefully designed and is not completely mathematical; it gives equal emphasis to the discussions around physics and creates a nice balance.

The book will be suitable for both undergraduate and graduate students taking courses in physics and chemistry. Several advanced topics have been covered in this book. They are expected to be beneficial particularly to graduate students and researchers.

Krishnendu Sengupta is Senior Professor at the Indian Association for the Cultivation of Science, Kolkata. His research interest includes theoretical condensed matter physics with emphasis on non-equilibrium dynamics of interacting quantum systems. He is a member of Indian National Science Academy, National Academy of Sciences, and Indian Academy of Sciences. He was awarded the Shanti Swarup Bhatnagar Award in 2012.

Palash B. Pal retired from the Saha Institute of Nuclear Physics, Kolkata, and is now Emeritus Professor at the University of Calcutta. His main area of research is elementary particle physics, with emphasis on neutrino properties, grand unification and thermal field theory. He has also published several pedagogical books, including *A Physicist's Introduction to Algebraic Structures* with the Press in 2019.

Introduction to Quantum Mechanics

Krishnendu Sengupta

Palash B. Pal

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE
UNIVERSITY PRESS

Shaftesbury Road, Cambridge CB2 8EA, United Kingdom
One Liberty Plaza, 20th Floor, New York, NY 10006, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre, New Delhi 110025, India
103 Penang Road, #05–06/07, Visioncrest Commercial, Singapore 238467

Cambridge University Press is part of Cambridge University Press & Assessment, a department of the University of Cambridge.

We share the University's mission to contribute to society through the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781009338424

First published 2023

Printed in India

A catalogue record for this publication is available from the British Library

ISBN 978-1-009-33842-4 Paperback

To the memories of

Pushan Majumdar and Manoranjan Saha

Cambridge University Press & Assessment
978-1-009-33842-4 — Introduction to Quantum Mechanics
Krishnendu Sengupta , Palash B. Pal
Frontmatter
More Information

Contents

Figures

Cambridge University Press & Assessment
978-1-009-33842-4 — Introduction to Quantum Mechanics
Krishnendu Sengupta , Palash B. Pal
Frontmatter
More Information

Tables

Notation

$\boldsymbol{p}$	3-vector in the coordinate space.
$\mathtt{p}$	Magnitude of the 3-vector $\boldsymbol{p}$, i.e., $\lvert\boldsymbol{p}\rvert$. We have used $\mathtt{p}^2$ and $\boldsymbol{p}^2$ interchangeably.
$\mathring{\boldsymbol{p}}$	Unit 3-vector in the direction of $\boldsymbol{p}$, i.e., $\boldsymbol{p}/\mathtt{p}$.
$\lvert u\rangle$	Ket vector.
$\langle u\rvert$	Bra vector.
$\lvert\Omega\rangle$	The null vector.
$\langle u\lvert v\rangle$	Inner product of two vectors.
$\widehat{A}$	Operator A on a vector space. In many places where confusion is not likely to arise, we have omitted the hat sign.
$\widehat{\boldsymbol{L}}$	An operator on a vector space that is also a vector in the coordinate space.
$A^\dagger$	Adjoint of the operator A, defined in §2.8.
$[A, B]_P$	Poisson bracket of A and B.
$[A, B]$	Commutator $AB - BA$.
$\{A, B\}$	Anticommutator $AB + BA$.
σ_i	Pauli matrices, given in Eq. (4.26, p. 87).
τ_i	Same as σ_i, but used when there is no connection with spin.
$\mathbb{S}$	Action of a system ($= \int dt\, L$).
e	Electric charge of proton. Electron carries charge $-e$.
α	Fine structure constant, first appearing in Eq. (9.63, p. 231).
$\lfloor x\rfloor$	The largest integer less than or equal to x.

Preface

Quantum mechanics is an essential part of any physics undergraduate or graduate curriculum for its wide range of applicability to different branches of physics. It is taught at different levels, starting from second or third year undergraduate to final year graduate programmes. Through these courses students learn to appreciate the details of the subject at various levels. It is therefore difficult to have a single book which caters to students at all levels. This gap is precisely what we aim to fill here.

The book bore out of several courses on quantum mechanics taught by both the authors at several institutions such as the Saha Institute of Nuclear Physics, the University of Calcutta, and the Indian Association for the Cultivation of Science. These included both undergraduate and graduate level courses. These courses made us realize the necessity of a book which not only provides a clear introduction to the basic tenets of the subject but also presents a thorough discussion of several advanced topics. The latter seemed particularly difficult to find in a single book, which served as a motivation for writing this book.

We have not included a discussion of the old quantum theory in our book. We assumed that the reader would be familiar with that development, which was initiated by Planck and Einstein. That theory deals with particle-like properties of energy. The subject matter of our book is the other side of the wave–particle duality that is the hallmark of modern physics, i.e., the theory which treats matter as waves. The title of this book clearly shows that this theory, 'quantum mechanics', will be the sole concern of this book.

Any book on quantum mechanics requires introduction to certain mathematical techniques such as group theory, linear algebra, and differential equations. We provide a somewhat detailed introduction to the first two topics since it is our understanding that these topics may not be taught in detail in other courses that physics students usually encounter before taking their first course on quantum mechanics. However, the last topic is usually well discussed in a generic physics curriculum; we have therefore relegated its discussion to the appendices, making every effort to keep it self-contained.

The book is divided into several parts. The first part introduces the formalism, while the second discusses exactly solvable problems. This is followed by a discussion of various approximation techniques in the third part and a discussion of several advanced topics in the fourth. Each part has several chapters with varying degrees of sophistication; however, we have made every attempt to make each of them self-contained so that it is possible for an instructor to choose the chapters according to the course requirement. The fifth part of the book contains appendices.

We have provided a large number of exercises for the reader. These will definitely help the beginner gain confidence in the subject. Instead of compiling all exercises at the end of each chapter, we have strewn them across the text. Solving any exercise at the place that it appears in the text, in our opinion, would be advantageous to the learner. If for some reason the reader does not want to solve the exercises, we recommend that at least the statement of the exercise should be read. In some cases, they contain important notes.

Over the years, many people have influenced our understanding of the subject, including our teachers, collaborators, and students. We would like to take this opportunity to express sincere thanks to all of them. This preface is too short to put forth all the names. During the time that we wrote this book, we have also received a lot of support from others. We are particularly thankful to Kumar Gupta, who has kindly read through all chapters of an earlier version and made important comments which resulted in a lot of rewriting. We also acknowledge useful discussions with, and helpful comments from, Jayanta Kumar Bhattacharjee, Arnab Das, Sumit Das, Asit De, Indrajit Mitra, Abhijit Mukherjee, Koushik Ray, Arnab Sen, and Parongama Sen. In addition, we thank the referees for their important comments and the publication team of Cambridge University Press for their support. Last but not least, we acknowledge the support of our spouses, Dora Saha and Shukla Sanyal, who tolerated our long working hours during the project.

The book was prepared camera-ready by us. This means that we are responsible for all mistakes that might have crept in, including typographical ones. If any reader finds a mistake, we will appreciate a message. We will maintain a webpage for corrections where such messages will be acknowledged. The address of the webpage is `https://sites.google.com/view/qmerrata` and is accessible to everyone.

Krishnendu Sengupta
April 2023 Palash B. Pal