Revolutions in Twentieth-Century Physics

The conceptual changes wrought by modern physics are radical, important, and fascinating, yet they are only vaguely understood by people working outside the field. Exploring the four pillars of modern physics – relativity, quantum mechanics, elementary particles, and cosmology – this clear and lively account, that will interest anyone who has wondered what Einstein, Schrödinger, Feynman, Hubble, and others were really talking about.

The book discusses quarks and leptons, antiparticles and Feynman diagrams, curved spacetime, the Big Bang and the expanding Universe. Suitable for undergraduate students on nonscience majors as well as science majors, it uses problems and worked examples to help readers develop an understanding of what recent advances in physics actually mean.

DAVID J. GRIFFITHS is an Emeritus Professor of Physics at Reed College. He is the author of three highly regarded physics textbooks: *Introduction to Electrodynamics* (fourth edition, Pearson, 2012), *Introduction to Quantum Mechanics* (second edition, Pearson, 2004), and *Introduction to Elementary Particles* (second edition, Wiley-VCH, 2008).

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University Printing House, Cambridge CB28BS,United Kingdom

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It furthers the University's mission by disseminating knowledge in the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781107602175

First published 2013
Reprinted 2015

Printed in the United States of America by Sheridan Books, Inc.

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

Library of Congress Cataloguing in Publication data
Griffiths, David J. (David Jeffery), 1942–
Revolutions in twentieth-century physics / David Griffiths, Reed College.
pages cm
Includes index.
ISBN 978-1-107-60217-5 (pbk.)
1. Quantum theory – Popular works. 2. General relativity (Physics) – Popular works.
I. Title.
QC174.12.G75154 2013
530 – dc23 2012030789

ISBN 978-1-107-60217-5 Paperback

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Preface

The twentieth century saw four astonishing revolutions in physics: relativity, quantum mechanics, elementary particles, and cosmology. Each one radically changed our understanding of the Universe. There were also, of course, extraordinary breakthroughs in technology (electronics, lasers, computers) that had a much larger influence on our daily lives, but did not carry the same conceptual impact.

This is a book about those four revolutions. It is intended for anyone with a serious interest in the great ideas that have shaped modern physics: advanced high school students or freshman physics majors who would like a taste of what lies ahead; undergraduates who do not intend to major in the sciences but are curious to know about some of the most profound intellectual achievements of our time; general readers who have heard about quarks and quanta, Albert Einstein and the Big Bang, and would like to know what all the fuss is about.

I should tell you up-front what this book is *not*. It is not another breathless account of the fantastic speculations that seem to dominate much of contemporary theoretical physics – things you may have read about, or seen on NOVA. Apart from a few footnotes and an occasional parenthetical remark, there is nothing here about superstrings or extra dimensions or multiple universes. We're dealing with well-established, robustly confirmed "facts." In a way, modern physics has been a victim of its own success. The revolutions described in this book account so perfectly for everything that is known about our world, that anyone hoping to come up with the next "great idea" is forced to rely more on imagination than on observation. There is nothing wrong with this – inspired conjecture occupies an honored place at the very pinnacle of scientific discovery. Pauli "predicted" the neutrino, Dirac the antiparticle, Yukawa the meson, and Gell-Mann the omega-minus and the quark, using nothing but pencil and paper, well before these particles were detected in the laboratory.

But I do think it is important to distinguish between "knowledge" and "speculation." Some authors leave the impression that you could buy a six-pack of black holes and a bag of Higgs bosons at any convenience store. No doubt many of the current conjectures will turn out to be true, but that's not what this book is about. It's about the rock solid foundations on which *any* future developments must inevitably rest. They are already astounding enough to make a great story.

This book is not for casual bed-time reading, and it is not for everyone. You need to know some mathematics – arithmetic for sure, and a little algebra in places. There is no honest way to explain this material without it. But if you are intimidated by the sight of an equation, please don't give up too quickly. Physics tends to seem extremely difficult when you first encounter it, but quite simple once you understand it. Understanding comes with familiarity and practice. There are quite a few problems sprinkled through the text, and I urge you to work them all. Students often tell me, "I understand the *concepts*; I just can't do the problems." They are fooling themselves. The only sure test of whether you understand the concepts is precisely your ability to work the problems. But it *does* take time and practice. There are no short cuts.

Modern physics is built on a venerable foundation going back to Galileo and Newton, so I begin with a survey of the essential ideas, laws, and terminology we inherit from the classical era. I don't pretend this is anywhere near complete – I will concentrate on those pieces of the subject that are essential to the story that follows. We need to know about mass and velocity, force and energy, momentum and wavelength, gravity and electric charge. These things are the focus of Chapter 1. The subsequent chapters treat relativity, quantum mechanics, elementary particles, and cosmology, in that order. In principle the sequence of these topics is interchangeable, but I think this roughly chronological ordering makes the best sense. However, if you are only interested in one or two of them, you should be able to read the chapters independently.

I thank the students in my Master of Arts in Liberal Studies (MALS) course, for whom much of this was written, and especially Trina Marmarelli, who read the first draft with great care and fixed many awkward passages.