# Modern Introductory Physics

Charles H. Holbrow • James N. Lloyd
Joseph C. Amato • Enrique Galvez
M. Elizabeth Parks

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Second Edition

Springer

Charles H. Holbrow
Charles A. Dana Professor of Physics, Emeritus
231 Pearl St.
Cambridge, Massachusetts 02139
USA
cholbrow@colgate.edu

James N. Lloyd
Professor of Physics, Emeritus
Colgate University
Department of Physics & Astronomy
37 University Ave.
Hamilton, New York 13346
USA
jlloyd@colgate.edu

Joseph C. Amato
William R. Kenan, Jr. Professor of Physics, Emeritus
Colgate University
Department of Physics & Astronomy
13 Oak Drive
Hamilton, New York 13346
USA
jamato@colgate.edu

Enrique Galvez
Professor of Physics
Colgate University
Department of Physics & Astronomy
13 Oak Drive
Hamilton, New York 13346
USA
egalvez@colgate.edu

M. Elizabeth Parks
Associate Professor of Physics
Colgate University
Department of Physics & Astronomy
13 Oak Drive
Hamilton, New York 13346
USA
meparks@colgate.edu

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. . . *all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another.*

In that one sentence, you will see, there is an *enormous* amount of information about the world, if just a little imagination and thinking are applied.

— Richard P. Feynman

# Preface

This book grew out of an ongoing effort to modernize Colgate University's three-term, introductory, calculus-level physics course. The book is for the first term of this course and is intended to help first-year college students make a good transition from high-school physics to university physics.

The book concentrates on the physics that explains why we believe that atoms exist and have the properties we ascribe to them. This story line, which motivates much of our professional research, has helped us limit the material presented to a more humane and more realistic amount than is presented in many beginning university physics courses. The theme of atoms also supports the presentation of more non-Newtonian topics and ideas than is customary in the first term of calculus-level physics. We think it is important and desirable to introduce students sooner than usual to some of the major ideas that shape contemporary physicists' views of the nature and behavior of matter. Here in the second decade of the twenty-first century such a goal seems particularly appropriate.

The quantum nature of atoms and light and the mysteries associated with quantum behavior clearly interest our students. By adding and emphasizing more modern content, we seek not only to present some of the physics that engages contemporary physicists but also to attract students to take more physics. Only a few of our beginning physics students come to us sharply focused on physics or astronomy. Nearly all of them, however, have taken physics in high school and found it interesting. Because we love physics and believe that its study will open students' minds to an extraordinary view of the world and the universe and also prepare them well for an enormous range of roles—citizen, manager, Wall-Street broker, lawyer, physician, engineer, professional scientist, teachers of all kinds—we want them all to choose undergraduate physics as a major.

We think the theme and content of this book help us to missionize more effectively by stimulating student interest. This approach also makes our weekly physics colloquia somewhat accessible to students before the end of their first year.[1]

In parallel with presenting more twentieth-century physics earlier than is usual in beginning physics, this book also emphasizes the exercise and development of skills of quantitative reasoning and analysis. Many of our students come fairly well prepared in both physics and math—an appreciable number have had some calculus—but they are often rusty in basic quantitative skills. Many quite capable students lack facility in working with powers-of-ten notation, performing simple algebraic manipulation, making and understanding scaling arguments, and applying the rudiments of trigonometry. The frustrations that result when such students are exposed to what we would like to think is "normal discourse" in a physics lecture or recitation clearly drive many of them out of physics. Therefore, in this first term of calculus-level physics we use very little calculus but strongly emphasize problems, order-of-magnitude calculations, and descriptions of physics that exercise students in basic quantitative skills.

To reduce the amount of confusing detail in the book, we often omit interesting (to the authors) facts that are not immediately pertinent to the topic under consideration. We also limit the precision with which we treat topics. If we think that a less precise presentation will give the student a better intuitive grasp of the physics, we use that approach. For example, for the physical quantities mass, length, time, and charge, we stress definitions more directly connected to perceivable experience and pay little attention to the detailed, technically correct SI definitions. This same emphasis on physical understanding guides us in our use of the history of physics. Many physical concepts and their interrelations require a historical framework if they are to be understood well. Often history illustrates how physics works by showing *how* we come to new knowledge. But if we think that the historical framework will hinder understanding, we take other approaches. This means that although we have tried diligently to

[1]These and other aspects of the approach of this book are discussed in more detail in C.H. Holbrow, J.C. Amato, E.J. Galvez, and J.N. Lloyd, "Modernizing introductory physics," *Am. J. Phys.* **63**, 1078–1090 (1995); J.C. Amato, E.J. Galvez, H. Helm, C.H. Holbrow, D.F. Holcomb, J.N. Lloyd and V.N. Mansfield, "Modern introductory physics at Colgate," pp. 153–157, *Conference on the Introductory Physics Course on the Occasion of the Retirement of Robert Resnick*, edited by Jack Wilson, John Wiley & Sons, Inc., New York, 1997; C.H. Holbrow and J.C. Amato, "Inward bound/outward bound: modern introductory physics at Colgate," in *The Changing Role of Physics Departments in Modern Universities*, pp. 615–622, Proceedings of International Conference on Undergraduate Physics Education, College Park, Maryland, August 1996, edited by E.F. Redish and J.S. Rigden, AIP Conference Proceedings **399**, Woodbury, New York, 1997.

avoid saying things that are flat out historically wrong, we do subordinate history to our pedagogical goals.

We believe that it is important for students to see how the ideas of physics are inferred from data and how data are acquired. Clarity and concision put limits on how much of this messy process beginning students should be exposed to, but we have attempted to introduce them to the realities of experimentation by including diagrams of apparatus and tables of data from actual experiments. Inference from tables and graphs of data is as important a quantitative skill as the others mentioned above.

Asking students to interpret data as physicists have (or might have) published them fits well with having beginning physics students use computer spreadsheets to analyze data and make graphical displays. Because computer spreadsheets are relatively easy to learn and are widely used outside of physics, knowledge of them is likely to be useful to our students whether they go on in physics or not. Therefore, we are willing to have our students take a little time from learning physics to learn to use a spreadsheet package. Some spreadsheet exercises are included as problems in this book.

The examination of significant experiments and their data is all very well, but nothing substitutes for actual experiences of observation and measurement. The ten or so laboratory experiments that we have developed to go along with this course are very important to its aims. This is particularly so, since we observe that increasingly our students come to us with little experience with actual physical phenomena and objects. We think it is critically important for students themselves to produce beams of electrons and bend them in magnetic fields, to create and measure interference patterns, to observe and measure electrolysis, etc. Therefore, although we believe our book will be useful without an accompanying laboratory, it is our heartfelt recommendation that there be one.

Although our book has been developed for the first of three terms of introductory physics taken by reasonably well-prepared and well-motivated students, it can be useful in other circumstances. The book is particularly suitable for students whose high-school physics has left them with a desire to know more physics, but not much more. For them a course based on this book can stand alone as an introduction to modern physics. The book can also work with less well prepared students if the material is spread out over two terms. Then the teacher can supplement the coverage of the material of the first several chapters and build a solid foundation for the last half of the book.

The format and techniques in which physics is presented strongly affect student learning. In teaching from this book we have used many innovative pedagogical ideas and techniques of the sort vigorously presented over many years by well-known physics pedagogues such as Arnold Arons, Lillian McDermott, Priscilla Laws, Eric Mazur, David Hestenes, and Alan van Heuvelen. In one form or another they emphasize actively engaging the students and shaping instruction in such a way as to force students to confront, recognize, and correct their misconceptions. To apply these ideas we teach the course as two lectures and two small-group recitations each week. In the lectures we use Mazur-style questions; in the recitations we have students work in-class exercises together; we spend considerable effort to make exams and special exercises reach deeper than simple numerical substitution.

Drawing on more than ten years of experience teaching from *Modern Introductory Physics*, we have significantly revised it. Our revisions correct errors in the 1999 edition and provide clearer language and more complete presentation of important concepts. We have also reordered the chapters on the discovery of the nucleus, the Bohr model of the atom, and the Heisenberg uncertainty principle to better tell the story of the ongoing discovery of the atom.

Our boldest innovation is the addition of two chapters on basic features of quantum mechanics. In the context of real experiments, these chapters introduce students to some of the profoundly puzzling consequences of quantum theory. Chapter 19 introduces superposition using Richard Feynman's approach; Chap. 20 discusses quantum entanglement, the violation of Bells inequalities, and experiments that vindicate quantum mechanics. Superposition, entanglement, non-locality, and Bell's inequalities are part of the remarkable success story of quantum mechanics. We want acquaintance with these important ideas to alert students to themes and technologies of twenty-first century physics. We want our book, which unfolds the ideas and discoveries that led to the quantum revolution, to end by opening for students a window into a future shaped by themes and emerging technologies that rely fundamentally on quantum mechanics.

Many colleagues helped us make this a more effective book with their useful critiques, problems, exercises, insights, or encouragement. For these we are grateful to Victor Mansfield (1941–2008), Hugh Helm (1931–2007), Shimon Malin, Stephen FitzGerald, Scott Lacey, Prabasaj Paul, Kurt Andresen, Pat Crotty, Jonathan Levine, Jeff Buboltz, and Ken Segall.

Deciding what specific subject matter should go into beginning physics has been a relatively small part of the past 30 years' lively discussions of pedagogical innovation in introductory physics. We hope our book will help to move this important concern further up the agenda of physics teachers. We think the content and subject emphases of introductory