physics

For Scientists and Engineers

An Interactive Approach

Second Edition

Hawkes
Iqbal
Mansour
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ROBERT HAWKES

Mount Allison University

JAVED IQBAL

University of British Columbia

FIRAS MANSOUR

University of Waterloo

MARINA MILNER-BOLOTIN

University of British Columbia

PETER WILLIAMS

Acadia University

NELSON

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by Robert Hawkes, Javed Iqbal, Firas Mansour, Marina Milner-Bolotin, and Peter Williams

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Suzanne Peden

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Preface

DEMYSTIFYING PHYSICS, A SCIENCE FOR LIFE

Physics is an exciting field that has changed our understanding of the world we live in and has immense implications for our everyday lives. We believe physics should be seen as the creative process that it is, and we aim to help the reader feel their own thrill of discovery.

To that end, *Physics for Scientist and Engineers: An Interactive Approach,* Second Edition, has taken a unique **student-first** development model. **Fundamental topics are developed gradually**, with great attention to the logical transition from the simple to the complex, and from the **intuitive to the mathematical**, all while highlighting the **interdisciplinary nature of physics**. This inquisitive and inspirational science is further supported with current events in Canada and beyond, and innovative pedagogy **based on Physics Education Research (PER)** such as **Interactive Activities**, **Checkpoints**, **unique problem-solving strategies** via open-ended problems, and ending **Examples** with "Making sense of the results."

HOW WE DO IT

Student-First Development Model

- The vision for this text was to develop it from the student perspective, providing the background, logical development of concepts, and sufficient rigour and challenge necessary to help students excel. It provides a significant array of engaging examples and original problems with varying levels of complexity.
- Students who are the primary users of educational textbooks have not traditionally been involved in their development. In *Physics for Scientists and Engineers: An Interactive Approach* we engaged Student Advisory Boards to evaluate the material **from a student perspective** and to develop the Peer to Peer boxes, which provide useful tips for navigating difficult concepts.
- One idea that spans a number of the PER-informed instructional strategies is **the value of student collaboration**. It is clear that learning is deeper when students develop ideas in collaboration with peers and work together both in brainstorming approaches and in developing solutions. This text has been written to encourage collaborative learning. For example, the open-ended problems and Interactive Activities are ideally suited to a group approach. The conceptual problems in each chapter are well suited for use in studio-style classrooms or in approaches that involve peer instruction strategies or interactive lectures. In some places, we have moved derivations from chapters to problems to encourage student discovery of key relationships. The simulations and experiment suggestions will encourage students to engage with the material in a meaningful way. For example, in Chapter 3 students are asked to answer their own questions by using motion detectors on their own smartphones. And with so many PhET simulations now accessible by mobile devices, students can extend their own investigations from the Interactive Activities.
- One goal of any book is to inspire students to appreciate the beauty of the subject and even go on to contribute and become leaders in the field. For this to be achieved, students must see the relevance of the subject. The strong interdisciplinary focus throughout the book will help students achieve this goal. At the same time, it is also important that **students can see themselves as future physicists**. This is a broad-market calculus-based introductory physics text written by a Canadian author team, and we have used Canadian and international examples highlighting physics discoveries, applications, notable scientists past and present, as well as contributions from young Canadians.
- Students place high value on **learning that will help them contribute to society**. For example, service learning is more popular than ever before, and a high number of students set goals of medical or social development careers. Also, there is strong public interest in such fundamental areas as particle physics, quantum mechanics, relativity, string theory, and cosmology. Revised and additional Making Connections boxes support the view of physics as a highly relevant, modern, and socially important field.

Gradual Development of Fundamental Topics

The following are some examples of how fundamental topics are developed in a way that mirrors how a student's own learning progresses, without overwhelming them up front.

- **Motion**: Chapters 3 and 4 have been reworked with an improved flow, logical structure, more diagrams, and consistent notation. Free body diagrams are now introduced in one dimension first (Chapter 5). Chapter 9 now develops angular momentum with an easy-to-grasp approach that includes student participation. The concept of rolling motion is covered from different angles in Chapter 9. Dedicating a chapter to rolling motion has allowed us to focus on and develop the subject gradually, starting with intuitive definitions related to everyday life. Problems that are commonly used at this level are offered in multiple versions with increasing difficulty, and novel open problems walk the student through powerful concepts such as spin and momentum.

- **Forces**: In the mechanics chapters, students are urged to consider how situations would feel. For example, prior to formally stating Newton's Third Law, the idea is qualitatively treated from the perspective of what happens when two friends on ice push each other.
- **Torque**: In Chapter 8, the often problematic concept of torque is introduced in a simple representation of the product of force and distance for the case where these are perpendicular. This is done with examples from everyday life. The discussion then evolves to treating the case where the force is not perpendicular to the displacement. The factors contributing to the torque exerted by a force are developed intuitively and presented using different perspectives, leading to the concept of the moment arm and the full vector representation of torque as the cross product between two vectors.
- **Inertia**: In Chapter 8, moment of inertia is introduced using the simple case of a rotating point mass. This leads intuitively to the moment of inertia of a collection of point masses. The point mass model is used to calculate the moment of inertia of a ring which is contrasted to the moment of inertia of a disk to aid with the intuitive appreciation of the radial distribution of mass on moments of inertia for simple cases. The moment of inertia of a ring is then calculated using integration, which is also applied to the calculation of the moment of inertia of a disk, and employed in the development of the parallel axis theorem.
- Treatment of **exoplanets** in Chapter 11 begins with a qualitative discussion before moving on to quantitative treatment and end-of-chapter problem material. Unique to introductory physics textbooks on the market, coverage of this concept also includes Canadian connections in the development of the field.
- **Gauss's Law**: Chapter 20 is now devoted to Gauss's law, and provides broader range of coverage including concepts that students may not have encountered in math courses (such as vector fields and surface integrals). We invoke an approach in introducing Gauss's law that is unique among introductory physics texts in Canada: We introduce the idea of flux through closed surfaces by first considering how many electric field lines are "caught" in different situations. This semi-quantitative treatment precedes the traditional mathematical treatment developed later in the chapter.
- **Capacitance** comes to life in Chapter 22 with qualitative treatment in two Interactive Activities, which reflects the approach of PhET simulations in general, and provides opportunity for both group and individual work—and further supported responses in the solutions manual.
- **Electromagnetism**: In Chapter 24, cross products relate more strongly to their use in earlier chapters; magnetic field calculations and interactions between fields and charges have been more thoroughly developed.
- While most texts cover the idea of historical **interferometers**, our treatment through the new Making Connection boxes in Section 29-1 (LIGO) and Section 30-10 (Detecting Gravitational Waves) is highly current and combines the basic idea of interferometers with the amazing technology allowing the precision of LIGO. We then provide quantitative treatment in the details of the first black hole coalescence detected by LIGO (and this is extended with a new problem at the end of the chapter).

Physics Education through an Interdisciplinary Lens

As the Canadian Association of Physicists Division of Physics Education (CAP DPE) and others have pointed out, the work of physicists—and the use of physics by other scientists, engineers, and professionals from related fields—is increasingly interdisciplinary. We aimed to **promote the interdisciplinary nature of physics** beyond simply having problem applications from various fields. Chapter content is presented with a rich interdisciplinary feel and stresses the need to use ideas from other sciences and related professions.

The diverse backgrounds of the author team help create this rich interdisciplinary environment, and we have employed many examples related to such fields as medicine, sports, sustainability, engineering, and even music. The text is also richer than most in coverage of areas such as relativity, particle physics, quantum physics, and cosmology.

Informed by the Latest in Physics Education Research

The text is written with Physics Education Research findings in mind, encouraging and supporting PER-informed instructional strategies. The author team brings considerable expertise to the project, including direct experience with a variety of PER-informed instructional strategies, such as peer response systems, computer simulations, interactive lecture demonstrations, online tutorial systems, collaborative learning, project-based approaches, and personalized system of instruction (PSI-based) approaches.

- While the text encourages PER-informed approaches, **it does not support only a single instructional strategy.** Instructors who use traditional lecture and laboratory approaches, those who use peer-response systems, those who favour interactive lecture demonstrations, and indeed those who use other approaches, will find the text well suited for their needs.
- The **visual program** throughout the text has been improved for clarity, consistency, use of colour as an instructional tool, and symbol handling. The Pedagogical Chart on the inside front cover of the text provides a summative quick-stop for student review when confronted with a complex figure, and supports more integration between chapters.

Unique Problem-Solving Approaches

While a professional physicist can view physics as a unified, small set of concepts that can be applied to a very diverse set of problems, the novice sees an immense number of loosely related facts. To guide students through this maze, this text is **concise in wording and emphasizes unifying principles and problem-solving approaches**.

- We have made most chapters self-contained so that each instructor can select which content is addressed in a course. A carefully selected set of problems, both conceptual and quantitative, helps to reinforce mastery of key concepts.
- While all physics texts strive to provide **"real-world problems,"** we believe that we have achieved this to a higher degree. This edition provides more consistent application of data-rich and open-ended problems, as well as improvements in quality, quantity, and richness of all questions and problems.
- Our **Open Problems** are modelled on how the world really is: a key part of applying physics is deciding what is relevant and making reasonable approximations as needed. Closed-form problems, which in most textbooks are the only type used, portray an artificial situation in which what is relevant—and only that—is given to the student.
- Our **Data-Rich Problems** and encouragement of the use of graphing, statistical, and numerical solution software help reinforce realistic situations.
- Our **Making Connections** boxes help students see and identify with real-life applications of the physics.

Interactive Learning

Modern computational tools play a key role in the lives of physicists and have been shown to be effective in promoting the learning of physics concepts. Data-Rich Problems teach students how to do computations, which students use to learn concepts and principles while exploring through PhET simulations and similar animation tools. These **allow students to develop their own conceptual understanding by manipulating variables in the simulated environments**. In the second edition, we use a wider range of PhET simulations and provide more complete guidance on each activity. We also number the simulations, which makes it easier for instructors to assign them to students.

Ultimately, students must take ownership of their learning; that is essentially the goal of all education. The strong links between objectives, sections, Checkpoint questions, and Examples provide an efficient environment for students to achieve this. We view our role in terms of maximizing student interest and engagement and eliminating obstacles on the road to active engagement with physics.

Robert Hawkes
Javed Iqbal
Firas Mansour
Marina Milner-Bolotin
Peter Williams
January 2018

KEY CHANGES TO THE SECOND EDITION

Throughout the Text

Reviewer feedback over the past four years has been valuable in identifying key trends used in classrooms today. That, along with additional PER resources and our own experiences in classrooms across Canada, has culminated in this new and vastly improved second edition. For example:

- We have expanded the array of examples and added significantly more challenging, high-calibre end-of-chapter problems that engage, inspire, and challenge students to attain a high level of proficiency, mastery, and excellence. The material on electromagnetism has been overhauled in this regard.
- **Examples** have been refined to be more consistent in structure, and with a more detailed approach to "Making sense of the result." This change was made to connect different problem-solving strategies to physics examples.
- **Significant digits** are implemented more consistently across chapters.
- We have made the use of **units** and **vector notation** consistent across all chapters. The use of vectors has been significantly revised in the first part of the text.

- We have enhanced cross-references between chapters and between topics and, when needed, between examples and problems within the chapters.
- The **art** throughout the text has been improved through clearer fonts, consistent terminology and symbols, and consistent use of colour and symbol handling. (See the Pedagogical Colour chart on the inside front cover of the book.)
- **Summaries** have been improved to better align with the Learning Objectives.
- **Data-Rich Problem**s and **Open Problems** have been incorporated into almost all chapters.
- **Interactive Activities** have been overhauled to make better use of online materials. In the text, they are now presented with a title and description of what is available online and what students will learn from it. If the Interactive Activity uses a PhET simulation, it is identified in the text. Once online, students will receive the interactive activity description and instructions in a detailed and segmented manner to help them work through it. Questions are asked at the end, and the solutions are provided to instructors only.
- New notations have been added to the **problems** at the end of chapters to identify when a problem involves d/dx differentiation, $\int$ integration, numerical approximation, and/or graphical analysis. This helps instructors select appropriate problems to assign.
- Heading structure has been improved, with top-level headings aligning with **Learning Objectives** in all chapters.
- More **Checkpoints** have been incorporated into the chapters.
- Each chapter now has at least one **Making Connections** box, and throughout the book this feature has been refined to reflect the latest developments in physics.
- All end-of-chapter problems have been carefully checked and improved with more detailed explanations in the Solutions Manual.

KEY CHAPTER CHANGES

Chapter 1 Introduction to Physics

- A new Making Connections on the 2015 Nobel Prize Winner in Physics, Art McDonald, has been added, as well as a Meet Some Physicists feature to show the diversity in physics-related careers.
- Sophistication of treatment of dimensional analysis and unit conversion has been improved, including additional examples and problems.
- On the suggestion of a reviewer, Approximations in Physics now has its own section and related problems.
- The number of problems and questions has approximately doubled in this chapter compared to the first edition, with a wide variety of types of problems.

Chapter 2 Scalars and Vectors

- The chapter has been improved through rechecking its examples, removing inconsistencies in notation and figures, and ensuring that all the subsections are aligned carefully with the learning objectives.
- The drawings of the free body diagrams and of corresponding life-like situations have been improved.
- One Making Connections, Longitude and Latitude on Earth, has been added.
- On the suggestion of the reviewers, the notation for vectors and their components has been changed, so vectors are always bold and italic with a vector sign over them (e.g., $\vec{\boldsymbol{a}}$), while their components are just italic (e.g., x_a).
- On the suggestion of the reviewers, the difficulty level in some of the problems has been adjusted.
- All problems and solutions have been checked, and careful attention has been paid to mathematically appropriate problems. Two new problems have been added, while three problems have been significantly changed to eliminate ambiguity. The chapter now has almost 70 problems.

Chapter 3 Motion in One Dimension

- This chapter has been extensively reworked, with enhanced attention to its logical structure, conceptual understanding, accuracy of the examples, and consistency of significant figures in the examples.
- The learning objectives have been clarified and aligned carefully with the flow of the chapter.
- A few Checkpoints connecting algebraic and graphical representations of motion have been added.
- A new vignette, additional examples, six Peer to Peer boxes, and two art- and nature-related Making Connections boxes have been added to connect one-dimensional motion to real life.
- Motion diagrams have been introduced and are used consistently throughout the chapter.
- A table illustrating the connection between the relative directions of an object's velocity and acceleration and their impact on the object's motion has been introduced (Table 3-3).
- A table summarizing the relationships between kinematics quantities has been added (Table 3-5).
- Examples of using modern technologies to evaluate the scale of the universe (Interactive Activity 3-1)

and analyze and visualize one-dimensional motion (e.g., Example 3-8, Section 3-6, Interactive Activities 3-3, 3-4) have been introduced.

- A video analysis technique to analyze motion is described, including a connection to the works of Eadweard Muybridge (Making Connections in Section 3-6).
- Some repetitive examples have been moved to the end-of-chapter problems or eliminated.
- Additional care has been taken regarding treatment of vector terms, and topics like the selection of the positive direction of motion have been clarified.
- The sections that require calculus (e.g., the analysis of motion with changing acceleration) have been isolated, so students will not find them distracting.
- All problems and solutions have been checked and attention paid to mathematically appropriate problems. A number of new problems have been added, and a number of others changed or eliminated. The difficulty level of all problems has been checked and adjusted where needed. The chapter has almost 140 problems.

Chapter 4 Motion in Two and Three Dimensions

- The graphical vector method for finding the trajectory of a projectile has been introduced.
- Video analysis of motion, including a data-rich problem, is utilized.
- New examples based on sports have been introduced.
- The relative motion discussion has been expanded.

Chapter 5 Forces and Motion

- This chapter has been extensively reworked, with enhanced attention to logical structure and care in explaining terms.
- The new Section 5-1 Dynamics and Forces introduces free body diagrams and net forces in one dimension, before going on to two and three dimensions.
- Additional care has been taken with vector terms and treatment, and topics like the selection of the positive direction have been clarified.
- For those who like to think of force as the derivative of linear momentum, a section (5-11 Momentum and Newton's Second Law) has been added. (Instructors who wish can delay this treatment until after momentum is covered in detail in Chapter 7.)
- A new section on component-free approaches has been added (5-5 Component-Free Solutions) that illustrates that vectors have meaning deeper than their component representations (it can be considered optional by those who do not want to cover this in first year).
- Several new Making Connections (e.g., Higgs boson) link this classical chapter to modern physics concepts.
- Fundamental and non-fundamental forces now have their own section (at the suggestion of a reviewer).
- The section on non-inertial reference frames has been reworked.
- A total of 28 examples richly illustrate all concepts and techniques for this important material.
- All problems and solutions have been checked and attention paid to mathematically appropriate problems. Over a dozen new problems have been added, and a number of others changed or eliminated. The chapter has more than 100 problems.

Chapter 6 Work and Energy

- This chapter now has an intuitive approach to work and energy, developing the idea of work, starting with the simple 1D situation and evolving into more complex situations.
- The discussion of the work-energy theorem, while sufficiently rigorous, is also intuitive and builds on what students have seen in earlier chapters.
- Vector formalism is employed in a way that encourages students to present their discussions using mathematical formulation.
- The chapter opener poses stimulating and intriguing questions regarding energy in general in a discussion that expands students' horizons while grounding the discussion in the discourse of the field.

Chapter 7 Linear Momentum, Collisions, and Systems of Particles

- The common form of the elastic collision equations is used.
- More examples, including two-dimensional inelastic collision, have been added.
- The centre of mass discussion has been expanded to include an example with a continuous mass distribution.

Chapter 8 Rotational Kinematics and Dynamics

- An intuitive development of torque has been added, examining the representations of torque in great detail using a variety of engaging illustrations and formualtions.
- The key concept of the moment arm is now fully developed in the chapter.

- A detailed exposure of the right-hand rule is now included in the chapter and connects well with the discussion on magnetic fields.

Chapter 9 Rolling Motion

- The chapter now develops the concepts of spin and orbital angular momentum using an intuitive and easy-to-grasp approach that allows active participation by students, but still with sufficient mathematical rigour. Sufficient emphasis is given to the power of the approach.
- Problems and examples now tie better into one another when it comes to considering more realistic approaches to a given scenario. Higher levels of complexity and rigour are included as needed.

Chapter 10 Equilibrium and Elasticity

- The topic of equilibrium is now introduced from an intuitive point of view, using real-life examples, and is exposed in a more complete fashion.
- The connection to the fully developed approach to torque in Chapter 8 is brought out more clearly. This is also summarized in the chapter for easy reference. The chapter now makes it easier to teach static equilibrium before rotational dynamics, as needed.

Chapter 11 Gravitation

- More quantitative treatment of elliptical orbits, and new derivations of Kepler's laws, have now been included.
- Classical treatment of black holes is now included in this chapter (this was in Chapter 29 only in the first edition).
- An expanded exoplanet section includes calculation of their masses.
- About 20 new problems and 4 new examples have been added in this chapter, with improvements in a number of others.

Chapter 12 Fluids

- The subsection "Solids and Fluids under Stress" has been added in Section 12-1.
- The subsection "A Simple Barometer" has been added in Section 12-3.
- Example 12-8 Weighing an Object Immersed in a Fluid has been added in Section 12-5.
- Example 12-9 Blood Flow through a Blocked Artery has been added in Section 12-8.
- Example 12-10 Water Pressure in a Home (Example 12-8 in the first edition) has been rewritten.
- We have replaced Example 12-11 (first edition) with a new example (Example 12-13 Pumping Blood to an Ostrich's Head) in the second edition.
- The subsection "Derivation of Poiseuille's Equation" has been added.
- Eleven new end-of-chapter problems have been added.

Chapter 13 Oscillations

- Example 13-1 (first edition) has been deleted.
- Section 13-6 The Simple Pendulum has been rewritten and expanded.
- Making Connections "Walking Motion and the Physical Pendulum" has been rewritten.
- The subsection "The Quality Factor or the Q-value" has been added in Section 13-9.
- Optional Section 13-11 Simple Harmonic Motion and Differential Equations has been added.
- Fourteen new end-of-chapter problems have been added.

Chapter 14 Waves

- A summary of the main results is provided at the start of Section 14-8.
- Optional Section 14-14 String Musical Instruments has been added.
- Optional Section 14-15 The Wave Equation in One-Dimension has been added.
- Eight new end-of-chapter problems have been added.

Chapter 15 Sound and Interference

- The art for many topics, including resonating columns, has been improved.
- A new section on the role of standing waves in musical instruments has been included.
- The discussion of determining sound levels due to multiple sources has been improved and expanded.

Chapter 16 Temperature and the Zeroth Law of Thermodynamics

- Consistency of wording has improved by use of the word "heat" for the energy that is transferred from one object to another.

Chapter 17 Heat, Work, and the First Law of Thermodynamics

- The sign of work and the convention adopted in the text have been clarified.

Chapter 18 Heat Engines and the Second Law of Thermodynamics

- Figure 18-3 is a detailed illustration showing a steam turbine in a CANDU nuclear power plant.

- Consistent colouring of heat flows in diagrams has been achieved.
- The discussion of the operation of a refrigerator expansion valve has been improved.

Chapter 19 Electric Fields and Forces

- Some topics have been reorganized and a new section added on charging objects by induction.
- Superposition has been added to the titles of Sections 19-4 and 19-7 as part of the enhanced treatment of vector superposition for electric forces and fields.
- A different symbol is used for linear charge density to agree with most other books.
- The electric field vector and field line diagrams are now in a section devoted just to that topic, with significantly enhanced treatment of electric field lines compared to the first edition.
- The number of example problems has more than doubled, as has the number of end-of-chapter problems and questions.
- A new short final section uses a new Checkpoint to clarify electric field misconceptions.

Chapter 20 (part of Chapter 18 in first edition) Gauss's Law

- A full chapter is now devoted to just this topic.
- A strong semi-quantitative base for electric flux is developed prior to the formal introduction of Gauss's law.
- Necessary math concepts such as vector fields, open and closed surfaces, symmetry types, and surface integrals are developed within the chapter for those who have not yet encountered them in their math courses.
- Common Gauss's law misconceptions are addressed through many additional Checkpoints.
- Symbols now differentiate calculation of surface integrals for open and closed surfaces.
- Section 20-9 introduces Gauss's law for gravity to illustrate application of the ideas in another area of physics.
- The chapter structure gives flexibility to instructors in how much of the subject is treated and how.
- There is now a good variety in types and difficulty level in questions and problems.
- In our opinion, we have one of the most complete and innovative treatments of Gauss's law in any introductory text.

Chapter 21 (part of Chapter 20 in first edition) Electric Potential Energy and Electric Potential

- The opening image relates the material of this chapter to the Large Hadron Collider.
- Rather than start right off with electrical potential energy, this chapter now opens with detailed calculations of work to move charges in electric fields. Both the work done by an external agent and the work done by an electric field are introduced, and the relationship between the two views is stated.
- A number of new Peer to Peer boxes and Checkpoints help eliminate misconceptions.
- The material has been enhanced and extended almost everywhere.
- We now include the method of images in the final section (21-9 Electric Potential: Powerful Ideas), but those who prefer not to cover this topic in first year can readily omit it without loss of continuity.
- The number of problems has been significantly expanded, with more than 100 in this chapter.

Chapter 22 (Chapter 21 in first edition) Capacitance

- While the overall structure of this chapter is only slightly changed from the first edition, there have been a large number of small improvements at the suggestion of reviewers and readers.
- We now use two different approaches to derive the electric field between the plates of an ideal parallel plate capacitor in Section 22-2 (one uses superposition and one does not). In this way, we establish where the electric charge must be on the plates as one of the important points summarized in bullet form at the end of the chapter.
- The notation for combining capacitors has been made consistent with that used later for combining resistors in Chapter 23.
- The Applications section has been altered, with a few topics that require resistance ideas eliminated.
- Almost 30 new problems have been added (and a few others changed).

Chapter 23 (Chapter 22 in the first edition) Electric Current and Fundamentals of DC Circuits

- The chapter has been improved through revising its examples by removing inconsistencies in notation and figures.
- The applications of Kirchhoff's laws have been clarified by using additional examples and improving the table clarifying the sign convention for the directions

of currents and the signs of potential differences across the circuit elements (Table 23-4).

- Nine new end-of-chapter problems have been added. The chapter now has more than 70 problems.

Chapter 24 (Chapter 23 in the first edition) Magnetic Fields and Magnetic Forces

- This chapter has undergone major revisions in terms of its content, examples, end-of-chapter problems, and solutions in the Solutions Manuals.
- The topic of cross products is developed intuitively as it relates to the chapter material and is closely linked to the development and use of cross products in earlier chapters.
- The presentation of magnetic field calculations and interactions between magnetic fields and moving charges is now done in much greater detail, evolving from the simple to the complex, and more comprehensively highlights the utility of the right-hand rule.
- The learning objectives have been edited and the sections are now better aligned with them.
- One new Checkpoint, two expanded examples, and two Making Connections boxes have been added, including a discussion of Canadian astronomer T. Victoria Kaspi and applications of magnetism to the animal kingdom.
- More than 30 figures in the chapter have either been added or edited and significantly improved.
- The discussion of the Hall effect has been significantly improved.
- More than 20 end-of-chapter problems of various complexity have been added, including a number of problems requiring differentiation and integration. The chapter now has more than 100 end-of chapter problems.

Chapter 25 (Chapter 24 in the first edition) Electromagnetic Induction

- While this chapter has not undergone major revisions, it has been edited for clarity and accuracy.
- The learning objectives have been edited, and the sections are now better aligned with these objectives.
- One new example in the chapter has been added, while all other examples have been edited for clarity, accuracy, and meaningful connections to everyday life and students' experiences.
- The figures and tables in the chapter have been clarified and improved.
- The chapter has more than 80 end-of-chapter problems of a wide range of difficulty, including a number of problems requiring differentiation and integration.

Chapter 26 Alternating Current Circuits

- Voltage is used in place of emf in this chapter, and this is explicitly discussed.
- Energy usage statistics have been updated.
- A new Checkpoint testing understanding of phase shifts has been added.

Chapter 27 Electromagnetic Waves and Maxwell's Equations

- In Section 27-8, we have added the Making Connections box "Polarization and 3D Movies."
- We have added five new end-of-chapter problems.

Chapter 28 (Chapter 27 in the first edition) Geometric Optics

- We have made relatively minor changes from a well-received first edition chapter.
- One extra Checkpoint question was added, and three examples have been improved.
- One Making Connections about image formation in plane mirrors has been edited and improved.
- All the tables summarizing sign conventions of geometric optics and properties of images created by mirrors and thin lenses have been improved.

Chapter 29 (Chapter 28 in first edition) Physical Optics

- We have made relatively minor changes from a well-received first edition chapter.
- The strategy for thin film interference problems is made explicit.
- Links with modern physics have been extended (e.g., a new Making Connections on the LIGO detector).
- More than 45 new end-of-chapter questions and problems have been added that are well distributed over all topics.

Chapter 30 (Chapter 29 in first edition) Relativity

- We retained consideration of both special relativity and some aspects of general relativity in this chapter, ending with the well-received quantitative example on the two relativistic corrections in the GPS system.

- As suggested by reviewers, we have provided more on the experimental evidence for relativity, including the new Making Connections box on the Hafele–Keating experiment ("Testing Time Dilation with Atomic Clocks").
- Lorentz transformations are now covered in depth with their own section. Those who prefer not to teach Lorentz transformations can skip Section 30-5 and the derivation in Section 30-8 and still cover the rest of the chapter.
- Matrix formulations are used for Lorentz transformations, which are also expressed without this notation for instructors who prefer not to use matrices in first year.
- At the suggestion of one reviewer, the relativistic velocity addition relationship is now fully derived in the text.
- Through a new qualitative problem we urge students to express arguments for and against the concept of relativistic mass.
- The spacetime diagram and interval coverage have been expanded.
- The relativistic Doppler shift is rigorously derived and has its own section.
- The term *four vector* is explained in the chapter.
- The relationship between total energy, relativistic momentum, and rest mass energy is now a key equation (30-38) and not simply part of a problem derivation, as it was in the first edition.
- An extensive new Making Connections quantitatively explains the evidence from the recent LIGO detection of black hole coalescence.
- There are about 30 new problems, along with changes and a few deletions from the first edition. There are four new examples.
- The Solutions Manuals have been totally reworked to make both the approach and the notation consistent between the Solutions Manuals and the chapter.
- We feel that we have one of the most comprehensive relativity treatments of any first-year textbook.

Chapter 31 Fundamental Discoveries of Modern Physics

- We have expanded the Fundamental Concepts and Relationships section to synthesize the results from the chapter, making it clearer why some new physics was needed.

Chapter 32 Introduction to Quantum Mechanics

- In Section 32-3, we have expanded the subsection "The Physical Meaning of the Wave Function."
- We have added Section 32-6 The Finite Square Well Potential, which includes the concept of the parity operation in quantum mechanics.
- We have added three new end-of-chapter problems.

Chapter 33 Introduction to Solid-State Physics

- We have replaced the formal derivation of the density of states at the Fermi surface with a more physical argument.

Chapter 34 Introduction to Nuclear Physics

- In Section 34-6, the subsection "Gamma Decay" from the first edition has been rewritten and is now called "Nuclear Levels and Gamma (γ) Decay."
- The new Section 34-7 Nuclear Stability has been added. The effect of Coulomb repulsion on the nuclear levels is discussed in this section.
- The new Section 34-10 Nuclear Medicine and Some Other Applications has been added.

Chapter 35 Introduction to Particle Physics

- Section 35-12 Beyond the Standard Model has been greatly expanded and contains the subsections "Dark Matter" and "Dark Energy."

About the Authors

Robert Hawkes Dr. Robert Hawkes is a Professor Emeritus of Physics at Mount Allison University. In addition to having extensive experience in teaching introductory physics, he has taught upper-level courses in mechanics, relativity, electricity and magnetism, electronics, signal processing, and astrophysics, as well as education courses in science methods and technology-enhanced learning. His astrophysics research program is in the area of solar system astrophysics, using advanced electro-optical devices to study atmospheric meteor ablation, as well as complementary lab-based techniques such as laser ablation. He is the author of more than 80 research papers. Dr. Hawkes received his B.Sc. (1972) and B.Ed. (1978) at Mount Allison University, and his M.Sc. (1974) and Ph.D. (1979) in physics from the University of Western Ontario. He has won a number of teaching awards, including a 3M STLHE National Teaching Fellowship, the Canadian Association of Physicists Medal for Excellence in Undergraduate Teaching, and the Science Atlantic University Teaching Award, as well as the Atlantic Award for Science Communication. He was an early adopter of several interactive physics teaching techniques, in particular collaborative learning in both introductory and advanced courses. The transition from student to professional physicist, authentic student research experiences, and informal science learning are recent research interests. He was a co-editor of the 2005 *Physics in Canada* special issue on physics education, and a member of the Canadian physics education revitalization task force. Minor planet 12014 is named Bobhawkes in his honour.

Outside physics and education, he combines walking and hiking with photography, and volunteers at a community non-profit newspaper. He treasures exploring the joy and fun of learning with his grandchildren.

Javed Iqbal Dr. Javed Iqbal is the director of the Science Co-op Program and an Adjunct Professor of Physics at the University of British Columbia (UBC). At UBC he has taught first-year physics for 20 years and has been instrumental in promoting the use of clickers at UBC and other Canadian universities. In 2004, he was awarded the Faculty of Science Excellence in Teaching Award. In 2012, he was awarded the Killam Teaching Prize. His research areas include theoretical nuclear physics, computational modelling of light scattering from nanostructures, and computational physics. Dr. Iqbal received his Doctoral Degree in Theoretical Nuclear Physics from Indiana University.

Firas Mansour As a lecturer in the Department of Physics and Astronomy at the University of Waterloo since 2000, Firas Mansour has gained respect and praise from his students for his exceptional teaching style. He currently teaches first-year physics classes to engineering, life science, and physical science students, as well as upper-year elective physics courses in the past. He is highly regarded for his quality of teaching, his enthusiasm in teaching, and his understanding of students' needs. His dedication to teaching is exemplary, as is his interest in outreach activities in taking scientific knowledge beyond the university boundary. He is a 2012 Distinguished Teaching Award recipient at the University of Waterloo. He has overseen the creation of high-quality material for online learning and face-to-face instruction and has implemented various PER–established practices ranging from flipped and blended classroom instruction to peer instruction and assessment and group work.

Marina Milner-bolotin Dr. Marina Milner-Bolotin is an Associate Professor in Science (Physics) Education at the Department of Curriculum and Pedagogy at the University of British Columbia. She holds an M.Sc. in theoretical physics from Kharkiv National University in Ukraine (1991), a teaching certification in physics and mathematics from Bar-Ilan University in Israel (1994), and a Ph.D. in mathematics and science education from the University of Texas at Austin (2001). She educates future physics and mathematics teachers and studies how modern technologies can be used to support physics learning and teaching, increasing student' interest in physics and their understanding of physics concepts and principles.

For the last 25 years, she has been teaching physics in Israel, the United States (Texas and New Jersey), and Canada (UBC and Ryerson University). She has taught physics and mathematics to a wide range of students, from gifted elementary students to university undergraduates and future physics teachers. She has also led a number of professional development activities for physics, science, and mathematics teachers in Ontario, British Columbia, and abroad. She is often invited to conduct professional development activities with science and mathematics teachers in China, the Republic of Korea, the United States, Iceland, Germany, Denmark, Israel, and other countries. In addition, Dr. Milner-Bolotin has led many science outreach events engaging the general public in physics. She founded the UBC Faculty of Science Faraday Christmas Lecture in 2004 and the UBC Faculty of Education Family Mathematics and Science Day in 2010.

She has published more than 50 peer-reviewed papers and 9 book chapters, and she led the development of online resources for mathematics and science teaching used by thousands of teachers and students: scienceres-edcp-educ.sites.olt.ubc.ca/.

She has served as the President of the British Columbia Association of Physics Teachers and as a member of the Executive Board of the American Association of Physics Teachers. She has received many teaching, research, and service awards, including the National Science Teaching Association Educational Technology Award (2006), the UBC Department of Physics and Astronomy Teaching Award (2007), the Ryerson University Teaching Excellence Award (2009), the Canadian Association of Physicists Undergraduate Teaching Medal (2010), the UBC Killam Teaching Award (2014), and the American Association of Physics Teachers Distinguished Service Citation (2014) and Fellowship (2016).

Peter Williams Dr. Peter Williams is Professor of Physics at Acadia University, where he also served as Dean of the Faculty of Pure and Applied Science between 2010 and 2016. He has received numerous awards for his teaching, including the 2006 Canadian Association of Physicists (CAP) Medal for Excellence in Teaching.

He played a critical role in the introduction of studio physics modes of instruction at Acadia University and has developed several innovative courses, including most recently a Physics of Sound course. He is very interested in effectively combining the best of technology-enhanced educational techniques while maintaining a strong personal approach to teaching. He is also a strong proponent of applying research methodology to the evaluation of the effectiveness of different modes of physics instruction and has published several articles in teaching journals.

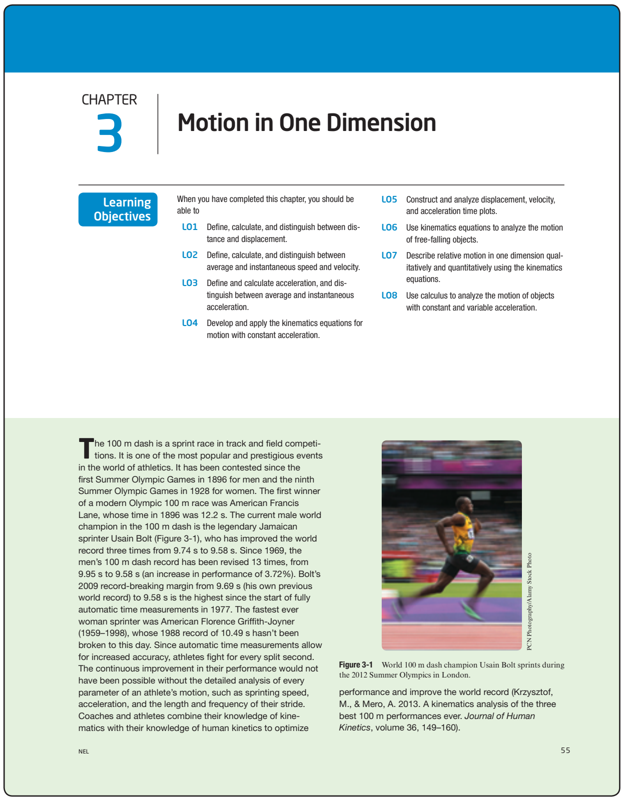
When he is not busy with physics, he loves to play his upright bass, go sailing with his family, and cook.

TEXT WALKTHROUGH

***Physics for Scientists and Engineers: An Interactive Approach*, Second Edition, is carefully organized so you can stay focused on the most important concepts and explore with strong pedagogy.**

Learning Objectives are brief numbered and directive goals or outcomes that students should take away from the chapter. Listed at the beginning of each chapter, these also correspond to major sections within that chapter.

Opening Vignettes These narratives at the beginning of each chapter introduce topics through an interesting and engaging real-life example that pertains to the chapter topics. An engaging entry into the chapter, these vignettes also provide students with the opportunity to read about historical and very recent current events in physics.



CHAPTER 3 | Motion in One Dimension

Learning Objectives

When you have completed this chapter, you should be able to

LO1 Define, calculate, and distinguish between distance and displacement.

LO2 Define, calculate, and distinguish between average and instantaneous speed and velocity.

LO3 Define and calculate acceleration, and distinguish between average and instantaneous acceleration.

LO4 Develop and apply the kinematics equations for motion with constant acceleration.

LO5 Construct and analyze displacement, velocity, and acceleration time plots.

LO6 Use kinematics equations to analyze the motion of free-falling objects.

LO7 Describe relative motion in one dimension qualitatively and quantitatively using the kinematics equations.

LO8 Use calculus to analyze the motion of objects with constant and variable acceleration.

The 100 m dash is a sprint race in track and field competitions. It is one of the most popular and prestigious events in the world of athletics. It has been contested since the first Summer Olympic Games in 1896 for men and the ninth Summer Olympic Games in 1928 for women. The first winner of a modern Olympic 100 m race was American Francis Lane, whose time in 1896 was 12.2 s. The current male world champion in the 100 m dash is the legendary Jamaican sprinter Usain Bolt (Figure 3-1), who has improved the world record three times from 9.74 s to 9.58 s. Since 1969, the men's 100 m dash record has been revised 13 times, from 9.95 s to 9.58 s (an increase in performance of 3.72%). Bolt's 2009 record-breaking margin from 9.69 s (his own previous world record) to 9.58 s is the highest since the start of fully automatic time measurements in 1977. The fastest ever woman sprinter was American Florence Griffith-Joyner (1959–1998), whose 1988 record of 10.49 s hasn't been broken to this day. Since automatic time measurements allow for increased accuracy, athletes fight for every split second. The continuous improvement in their performance would not have been possible without the detailed analysis of every parameter of an athlete's motion, such as sprinting speed, acceleration, and the length and frequency of their stride. Coaches and athletes combine their knowledge of kinematics with their knowledge of human kinetics to optimize performance and improve the world record (Krzysztof, M., & Mero, A. 2013. A kinematics analysis of the three best 100 m performances ever. *Journal of Human Kinetics*, volume 36, 149–160).

PCN Photography/Alamy Stock Photo

Figure 3-1 World 100 m dash champion Usain Bolt sprints during the 2012 Summer Olympics in London.

NEL 55

Examples Each example is numbered and corresponds to each major concept introduced in the section. Examples are now more consistently structured across all chapters, with a title, a statement of the problem, a solution, and a paragraph titled "Making sense of the result." Within the example, the authors have modelled desired traits, such as care with units and consideration of appropriate significant figures. "Making sense of the result" is one of the most important features, in which authors model the idea of always considering what has been calculated to determine whether it is reasonable.

EXAMPLE 15-2

Wave Amplitude

Calculate the displacement amplitude of a 1000 Hz sound wave whose pressure amplitude is 100.0 μPa.

Solution

This is a simple application of the relationship expressed in Equation 15-11. Using the bulk modulus for air found in Table 15-1, we rearrange Equation 15-11 to find

$$A = \frac{\Delta p}{Bk} = \frac{\Delta p_m}{B\dfrac{2\pi f}{v}} = \frac{0.000\,1000 \text{ Pa}}{1.41 \times 10^5 \text{ Pa}\,\dfrac{2\pi(1000 \text{ s}^{-1})}{343 \text{ m}\cdot\text{s}^{-1}}}$$

$$= 3.87 \times 10^{-11} \text{ m}$$

Making sense of the result

We have a pressure amplitude that is about four times that shown in Figure 15-4. Since the pressure amplitude is proportional to the displacement amplitude, we should find a displacement amplitude that is four times that shown in Figure 15-4.

Peer to Peer Written by students for students, Peer to Peer boxes provide useful tips for navigating difficult concepts.

PEER TO PEER

In doing relativistic trip type problems, I find the most important thing is to keep in mind the definitions of proper length and proper time. The person on the trip measures the proper time (if the time interval is the trip), but a different observer not moving with respect to the end points of the trip measures the proper length.

Making Connections Making Connections boxes are provided in a narrative format and contain concise examples from international contexts, the history of physics, daily life, and other sciences.

MAKING CONNECTIONS

Measuring the Speed of Neutron Stars

The Chandra X-ray Observatory detected a neutron star, RX J0822-4300, which is moving away from the centre of Pupis A, a supernova remnant about 7000 ly away (Figure 3-14). Believed to be propelled by the strength of the lopsided supernova explosion that created it, this neutron star is moving at a speed of about 4.8 million km/h (0.44% of the speed of light, 0.44*c*), putting it among the fastest-moving stars ever observed. At this speed, its trajectory will take it out of the Milky Way galaxy in a few million years. Astronomers were able to estimate its speed by measuring its position over a period of 5 years.

Figure 3-14 Supernova remnant RX J0822-4300.

Checkpoints Each learning objective has a Checkpoint box to test students' understanding of the material they have just read. Checkpoint boxes include questions in different formats, followed immediately by the answer placed upside down at the end of the box. While different formats are used, these Checkpoints are meant to be self-administered, so they all have a single clear answer so that students know whether they have mastered the concept before moving on to dependent material. The close linking of sections, learning objectives, and Checkpoints is a major feature of the text.

CHECKPOINT 23-3

Ranking Resistances of Metal Wires

Which of the following statements correctly represents the ranking of the resistances of the five copper wires shown in Figure 23-7? Notice that *D* in Figure 23-7 represents the diameter of the wire. How would you rank the resistivities of these wires?

(a) $R_b > R_a = R_e > R_c > R_d$
(b) $R_b > R_a > R_e > R_c > R_d$
(c) $R_c > R_a = R_e > R_b > R_d$
(d) $R_d > R_c > R_e = R_a > R_b$
(e) $R_d > R_a = R_e > R_c > R_b$

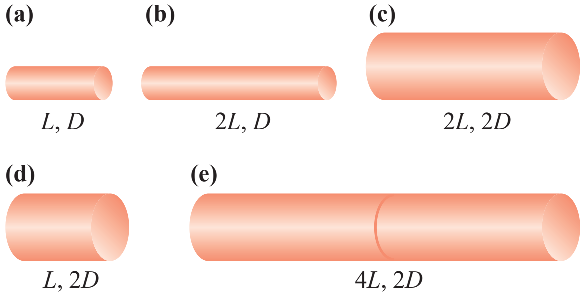


Figure 23-7 Checkpoint 23-3.

ANSWER: (a) Use Equation 23-16 to compare the resistances. The resistivities of the wires are the same because they are made from the same material.

Interactive Activities provide activities, such as computer simulations, that help with concept development. Many of these are matched to the research-validated PhET simulations. Students are introduced to an Interactive Activity in the text, and then when online, they will see a full description and set of instructions embedded with the activity, so they can adjust variables or diagrams provided. Questions are provided at the end. Answers are available to instructors only.

INTERACTIVE ACTIVITY 11-4

Sun, Planet, and Comet

In this activity, you will use the PhET simulation "My Solar System" to animate a three-body system with the Sun, a planet, and a much smaller mass comet. You will see how the orbit of the comet changes depending on how similar the planet and comet masses are. Through this activity you are introduced to the concept of gravitational **precession**, an idea that played a crucial role in the establishment of general relativity (Chapter 30).

Key Equations It is important for students to differentiate fundamental relationships from equations that are used in steps of derivations and examples. Key equations are clearly indicated.

KEY EQUATION

$$T^2 = \frac{4\pi^2}{G(m_1 + m_2)} a^3 \quad (11\text{-}37)$$

Key Concepts and Relationships provide a summary at the end of each chapter. This section provides students with an opportunity to review the key concepts discussed in the chapter. Care has been taken to make these concise and yet at the same time cover all core ideas and correspond to major sections in the chapter. Applications and Key Terms introduced in that chapter are also listed here for student reference.

KEY CONCEPTS AND RELATIONSHIPS

Kinematics is the study of motion. In kinematics, we study the relationships between an object's position, displacement, velocity, and acceleration and their dependence on time. We also examine relative motion.

End-of-Chapter Questions and Problems Questions, Problems by Section, Comprehensive Problems, Data-Rich Problems, and Open Problems are provided at the end of each chapter to test students' understanding of the material. The volume of exercises and problems has been significantly expanded in this edition.

For the problems, star ratings are used (*, **, or ***), with more stars indicating more-challenging problems. New to this edition, problems now include notation to identify if they involve $\frac{d}{dx}$ differentiation, $\int$ integration, numerical approximation, and/or graphical analysis.

QUESTIONS

1. A sound wave is a longitudinal wave. True or false?
2. The displacement and pressure amplitudes are
   (a) in phase
   (b) out of phase by 90°
   (c) out of phase by 180°
3. When we double the frequency of a sound wave, by what factor does the wavelength change?

PROBLEMS BY SECTION

For problems, star ratings will be used (★, ★★, or ★★★), with more stars meaning more challenging problems. The following codes will indicate if $\frac{d}{dx}$ differentiation, $\int$ integration, numerical approximation, or graphical analysis will be required to solve the problem.

Section 15-1 Sound Waves

15. ★ A wave is observed to have a frequency of 1000 Hz in air. What is the wavelength?

COMPREHENSIVE PROBLEMS

42. ★ At large concerts, it is sometimes disconcerting to observe the musicians moving apparently out of sync with the music. This results from the time it takes the sound to travel from the stage to you. When the musicians are playing at 100 beats/min, at what distance from the stage will they appear to be one full beat behind?

DATA-RICH PROBLEM

68. ★★★ You have been hired by an environmental consulting firm to do a noise analysis for a quarry operation. The operation uses two trucks, a drill, and a crusher. The manufacturers of the equipment provided the specifications in Table 15-5 for the sound level of the various pieces of equipment. Local bylaws specify that the maximum sound level at the perimeter of the quarry property not exceed 85 dB. How close to the perimeter can the quarry operate all these devices simultaneously?

Table 15-5 Data for Problem 68

Equipment	Sound Level at 10 m
Truck	85 dB
Drill	110 dB
Crusher	110 dB

OPEN PROBLEM

69. ★★★ Many of us have heard the effect that can be produced by inhaling helium and speaking. The speaker's voice is shifted to higher frequencies. Discuss the physics behind this effect.

ACKNOWLEDGMENTS

The Nelson Education team has been amazing—this book would never have been completed without their expertise, attention to detail, flexibility, and above all emphasis on producing a high-quality and innovative text. Particular credit goes to Paul Fam, Senior Publisher—Higher Education, who has so enthusiastically guided and supported the project from the earliest days. Content Manager Suzanne Simpson Millar's extensive experience and professionalism were critical in moving us from rough drafts to finished manuscript.

A text written by a team of physicists poses a challenge in making the final book have a common voice and a consistent approach. The success we have achieved in that regard is due in large part to our copyeditor, Julia Cochrane. Words cannot adequately express the debt we owe. The production stage was complex, and we thank the many people who helped us through this process—often under tight deadlines—especially Production Project Managers Wendy Yano and Natalia Denesiuk Harris, who had primary responsibility for overall production issues. Kristiina Paul, our photo researcher, worked hard to get permissions for our first choices for images and, when they were not available, to find suitable alternatives. The publisher and the author team would also like to convey their thanks to Simon Friesen, University of Waterloo; Karim Jaffer, John Abbott College; Anna Kiefte, Acadia University; and Kamal Mroue, University of Waterloo, for their technical edits, which ensured consistency in key areas, such as the use of significant digits, accuracy in the figures, and making sure all of the steps were accounted for in the examples presented and solutions prepared.

Thanks go to those who reviewed the text. Collectively, these professionals offered ideas, and occasional corrections, that helped make the book more accurate and clear. The diversity of their views of physics and how it should be taught—while occasionally resulting in not all suggestions being able to be incorporated in this printing—provided us with a broader view than that of the five authors alone. We give thanks to the following individuals:

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Members of the UBC Student Advisory Board (SAB) helped us remain grounded in what sort of text students wanted and would use, and most of them also contributed to the Peer to Peer boxes, ensuring that the material in this text is presented from a truly "student" perspective.

We thank Kimberley Carruthers, Marketing Manager at Nelson Education, for her skilled promotion of the book, along with the team of publisher's sales representatives across the country.

To be honest, this book has taken more of our time and energy than any of the authors ever anticipated. All of the authors combined the writing of this text with other career demands, and as a result many weekends and evenings were devoted to this text. We thank our family members for their understanding and encouragement. We thank our colleagues for their support in various ways during the course of this project. The authors would also like to acknowledge Rohan Jayasundera and Simarjeet Saini for enlightening discussions. The authors would like to thank Olga Myhaylovska for her valuable input and advice. The authors would also like to thank Reema Deol and Renee Chu for conducting background research on some of the material used in the text.

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Daily in our classrooms we learn from our students and are rejuvenated by their enthusiasm, creativity, and energy. Our view of the teaching and learning of physics owes a great deal to them, probably more than they realize. Similarly, our interactions with colleagues, both at our own institutions and beyond, have shown us new and more effective ways to approach difficult concepts and helped in our own education as physicists. We would like to acknowledge the valuable work done by organizations such as the Canadian Association of Physicists Division of Physics Education (CAP DPE) and the American Association of Physics Teachers (AAPT).

INSTRUCTOR RESOURCES

The **Nelson Education Teaching Advantage (NETA)** program delivers research-based instructor resources that promote student engagement and higher-order thinking to enable the success of Canadian students and educators. Visit Nelson Education's **Inspired Instruction** website at nelson.com/inspired/ to find out more about NETA.

The following instructor resources have been created for *Physics for Scientists and Engineers: An Interactive Approach*, Second Edition. Access these ultimate tools for customizing lectures and presentations at nelson.com/instructor.

NETA Test Bank

This resource was written by Karim Jaffer, John Abbot College. It includes more than 1,000 multiple-choice questions written according to NETA guidelines for effective construction and development of higher-order questions. Also included are 500 true/false questions.

The NETA Test Bank is available in a new, cloud-based platform. **Nelson Testing Powered by Cognero®** is a secure online testing system that allows instructors to author, edit, and manage test bank content from anywhere Internet access is available. No special installations or downloads are needed, and the desktop-inspired interface, with its drop-down menus and familiar, intuitive tools, allows instructors to create and manage tests with ease. Multiple test versions can be created in an instant, and content can be imported or exported into other systems. Tests can be delivered from a learning management system, the classroom, or wherever an instructor chooses. Nelson Testing Powered by Cognero for *Physics for Scientists and Engineers: An Interactive Approach*, Second Edition, can be accessed through nelson.com/instructor.

NETA PowerPoint

Microsoft® PowerPoint® lecture slides for every chapter have been developed by Sean Stotyn, University of Calgary. There is an average of 55 slides per chapter, many featuring key figures, tables, and photographs from *Physics for Scientists and Engineers: An Interactive Approach*, Second Edition. Notes are used extensively to provide additional information or references to corresponding material elsewhere. NETA principles of clear design and engaging content have been incorporated throughout, making it simple for instructors to customize the deck for their courses.

Image Library

This resource consists of digital copies of figures, short tables, and photographs used in the book. Instructors may use these jpegs to customize the NETA PowerPoint or create their own PowerPoint presentations. An Image Library Key describes the images and lists the codes under which the jpegs are saved.

TurningPoint® Slides

TurningPoint® classroom response software has been customized for *Physics for Scientists and Engineers: An Interactive Approach*, Second Edition. Instructors can author, deliver, show, access, and grade, all in PowerPoint, with no toggling back and forth between screens. With JoinIn, instructors are no longer tied to their computers. Instead, instructors can walk about the classroom and lecture at the same time, showing slides and collecting and displaying responses with ease. Anyone who can use PowerPoint can also use JoinIn on TurningPoint.

Instructor's Solutions Manual

This manual, prepared by the textbook authors, has been independently checked for accuracy by Simon Friesen, University of Waterloo; Karim Jaffer, John Abbott College; Anna Kiefte, Acadia University; and Kamal Mroue, University of Waterloo. It contains complete solutions to questions, exercises, problems, Interactive Activities, and Data-Rich Problems.

Möbius

Möbius allows you to integrate powerful, dynamic learning and assessment tools throughout your online course materials, so your students receive constant feedback that keeps them engaged and on track.

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placement and remediation programs, independent learning, outreach programs, and flipped or blended classrooms.

- Provide exactly the content you want, from individual lessons and textbook supplements, to full courses, remedial materials, enrichment content, and more.
- Choose the learning experience by allowing students open access to your course material or guiding them along a specific learning path.
- Stay in control of your content, creating and customizing materials as you wish to suit your needs.

STUDENT ANCILLARIES

Student Solutions Manual (ISBN 978-0-17-677046-4)

The Student Solutions Manual contains solutions to selected odd-numbered exercises and problems.

Möbius

Möbius is an HTML5-native online courseware environment that takes a "learn-by-doing" philosophy to STEM education, utilizing the highly interactive Maple visualization engine that drives online applications for immediate learning outcome development and assessment. It also harnesses the power of the Maple TA™ platform, enabling over 15 different types of algorithmic assessments that can be posed to a student at any time within the courseware environment. The power of the assessment is immediate confirmed understanding of difficult STEM-based topics in real time. This type of power is necessary to ensure the high level of learning outcomes that is possible within the environment. Instructors can easily create and share their own assessments and modify any lesson, assessment, or interactive activity and share with their students or the wider Möbius user community. In addition, unlike traditional learning technologies, textbook exposition, interactives (i.e., PhET simulations), and assessment are all "in line" so that students are presented with a unified learning environment, keeping them firmly focused on the topic at hand.

CHAPTER 1 Introduction to Physics

Learning Objectives

When you have completed this chapter, you should be able to

LO1 Define what we mean by physics in your own words.

LO2 List the types of possible errors, and differentiate between precision and accuracy.

LO3 Calculate the mean, standard deviation, and standard deviation of the mean (SDOM) for data sets, and correctly use ± notation and error bars.

LO4 Correctly apply significant digits rules to calculated quantities.

LO5 Convert quantities to and from scientific notation.

LO6 State SI units, and write the units and their abbreviations correctly.

LO7 Apply dimensional analysis to determine if a proposed relationship is possible.

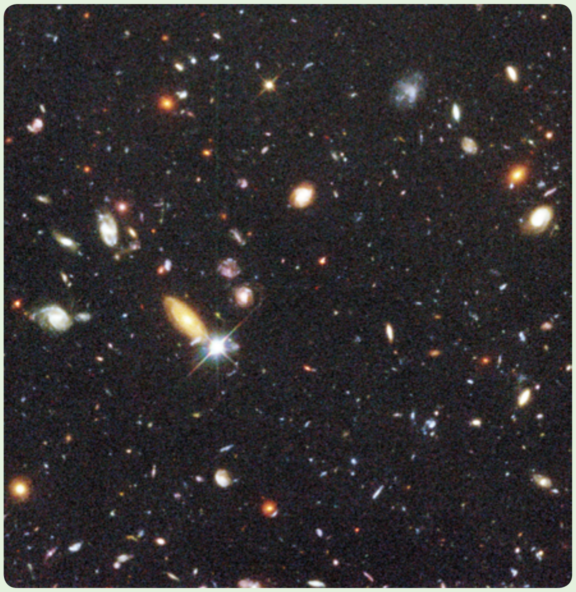
LO8 Perform unit conversions.

LO9 List and explain reasons why we make approximations in physics.

LO10 Make reasonable order-of-magnitude estimates and solve open problems.

Why should you study physics? One reason is that physics helps us answer amazing questions. For example, physics has provided a remarkably detailed picture of what the universe is like and how it has developed over time. The Hubble Space Telescope produced the image in Figure 1-1. The image shows an area of the sky equivalent to what you would cover if you held a 1 mm square at arm's length. Yet this image shows about 10 000 galaxies, and each galaxy typically contains 100 billion stars. In the hundred years since the first evidence of the existence of galaxies, observations and theoretical calculations by numerous physicists have provided strong evidence that the evolution of the universe started in a "big bang" about 13.8 billion years ago, when the universe was infinitesimally small, almost infinitely dense, and incredibly hot.

Like cosmology, aspects of research in particle physics, quantum mechanics, and relativity can be fascinating because they challenge our common-sense ideas. However, discoveries in these fields have also led to numerous extremely useful applications. For example, atomic physics underlies medical imaging technologies from simple X-rays to the latest MRIs and CAT scans. In fact, physics concepts are the basis for almost all technologies, including energy production and telecommunications. As you explore this book, each chapter will bring a new answer to the question, "Why should physics matter to me?"



Robert Williams and the Hubble Deep Field Team (STScI) and NASA

Figure 1-1 A tiny part of the night sky captured with incredible detail by the Hubble Space Telescope.

1-1 What Is Physics?

We will start this chapter by considering the nature of physics, and what differentiates physics from other areas of study.

The domain of physics is the physical universe The domain of physics extends from the smallest subatomic particles to the universe as a whole. Physics does not seek to answer questions of religion, literature, or social organization. While physics is creative, and we may refer to the art of physics and recognize artistic beauty in conceptual frameworks, there is a fundamental difference between art and physics. Art can be created in any form envisioned by the artist, but physics must comply with the nature of the physical universe. Nor is mathematics or philosophy the same as physics. Most argue that for something to be considered physics, it must, at least potentially, be validated through observations and measurements. Not everyone in physics agrees about this last point. There has been recent debate about whether aspects of string theory and multiverses (parallel universes) are properly considered physics.

Physics is a quantitative discipline Although there are a few topics in physics where our understanding is currently mainly qualitative, overall, measurement and calculation play critical roles in developing and testing physics ideas. Most physicists spend more time performing computations than they spend on any other single aspect of physics. Although all sciences and engineering are increasingly mathematically sophisticated, most would agree that physics is the most mathematical of the sciences.

Associated with quantitative reasoning must be the recognition that there is an inherent uncertainty in any measured quantity. Later in this chapter we will explore how to determine the uncertainty in common situations and to express that uncertainty in how you write a number.

Physics uses equations extensively to express ideas You should view physics equations as a shorthand notation for the theories and relationships they represent. While we can express physics concepts in words, it is more efficient, particularly in situations simultaneously involving a number of different physics ideas, to use equation notation. You will need to develop proficiency in manipulating equations and deriving relationships from basic principles. Applying physics, though, is not simply selecting from a large pool of established equations. You should always ask yourself whether a relationship is applicable to the situation, and what assumptions are inherent in using any particular equation. It is a good idea to start every problem by considering the physics concepts that

MAKING CONNECTIONS

Meet Fabiola Gianotti

Italian physicist Fabiola Gianotti (Figure 1-2) was until recently the scientific spokesperson for the ATLAS experiment at the LHC at CERN (Conseil Européen pour la Recherche Nucléaire) and she is now Director General at CERN, arguably the world's most important scientific undertaking. Even during her university studies, Fabiola Gianotti was undecided between a career in the creative arts, in philosophy, in other sciences, or in physics. She is a skilled pianist and studied piano at the Milan Conservatory. She is quoted as saying that her interest in philosophy helped her see that asking the right questions was critical, a view that has shaped her success in physics. She feels that it is sometimes misunderstood how close physics is to the arts: "… art and physics are much closer than you would think. Art is based on very clear, mathematical principles like proportion and harmony. At the same time, physicists need to be inventive, to have ideas, to have some fantasy." She is excited about the progress that physics has made in understanding our universe but realizes that much remains to be done: "… what we know is really very, very little compared to what we still have to know."

Courtesy Mike Struik

Figure 1-2 Director General at CERN Fabiola Gianotti.

MAKING CONNECTIONS

The CCD: Applied Physics and a Nobel Prize

The 2009 Nobel Prize in Physics was awarded to three scientists: the late Canadian Willard S. Boyle and the American George E. Smith for the invention of the charge coupled device (CCD) (see Figure 1-3), and Charles Kuen Kao from China for work leading to fibre-optic communication. Born in Amherst, Nova Scotia, Willard Boyle studied at McGill University before working at Bell Laboratories in New Jersey, where he and Smith made the first CCD.

The CCD is a semiconductor device with many rows, each consisting of a large number of tiny cells that accumulate an electric charge proportional to the light intensity at each cell (see Chapter 22). The CCD is the heart of digital cameras. A fundamental obstacle to digital imaging was that it was not practical to connect one wire to each of the millions of pixels that make up the digital image. This problem was overcome through the CCD invented by Dr. Boyle and colleagues.

The key idea is that the electric charge, representing the brightness of the image, is passed from one cell to the next. It is as though you have a line of people, each with a number written on a piece of paper, and you want to read out the codes from all of the papers. One approach is to have each person hand their paper to the person beside them in sequence, all down a line, and collect all the papers at a single point. The cells in a CCD do this with electric charge—a sequence of voltage pulses applied to the CCD cells causes the charge in each cell to transfer to the next cell in the row. The charge sequence leaving the last cell produces a signal that corresponds to the light that was focused on all the different cells in the line (signals can be moved from line to line in a similar manner). This signal is amplified to make an electronic record of the image that was stored as charge on the CCD.

CCD imaging has many advantages over film, including substantially greater sensitivity, linearity (meaning twice as much light produces twice as much signal), and the ability to be remotely operated, essential for applications such as space cameras. CCDs are the heart of all space telescopes and many medical instruments, as well as consumer devices containing digital cameras.

(a)

(b)

OLIVIER MORIN/Staff/Getty Images

Figure 1-3 (a) An image of Comet 67P/Churyumov–Gerasimenko taken with a charge coupled device (CCD) digital camera on the ESA Rosetta mission. (b) Willard Boyle (left) and George Smith in 1970, shortly after their invention of the CCD.

Source: (a) European Space Agency – ESA. This work is licenced under the Creative Commons Attribution-ShareAlike 3.0 IGO (CC BY-SA 3.0 IGO) licence: http://creativecommons.org/licenses/by-sa/3.0/igo/

may be helpful, rather than starting with equations. Although equations form the language of physics, the heart of physics is made up of the physical concepts the equations represent. An analogy might be you and your name; it is efficient for others to refer to you by your name, but the important thing is who you are, not your name.

Models, predictions, and validation Physicists develop hypotheses and models based on patterns recognized in observations and experiments. From these hypotheses and models they develop predictions that can be tested with further measurements. If the additional measurements are not consistent with the predictions, our model must be wrong, or at least inadequate. It is important to realize that "proof" in physics is never absolute. We can prove that a model or hypothesis is wrong through predictions and experiments, but we cannot prove it is absolutely right. We do develop confidence in models that have been used for many predictions, all of which have been found consistent with experiment, but that is not the same as

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saying we are sure the model will hold up in all possible future experiments and situations. For example, in Chapter 30 you will learn about general relativity and see that it has been used to predict a number of results that are contrary to common sense. Most of these have now been tested, and passed those tests, so we do have confidence in general relativity, but that is not the same as saying we are sure the theory is necessarily complete.

Physics seeks explanations with the greatest simplicity and widest realm of application Those from outside physics often view physics, incorrectly, as a collection of a large number of laws. Rather, physics seeks to explain the physical universe and all that it contains using a limited number of relationships. For example, we only need to invoke four types of interactions to explain all forces in physics: gravitation, electromagnetism, weak nuclear forces, and strong nuclear forces. Many physicists believe that ultimately these can be brought together as different aspects of a single unified theory. In your study of physics it is critical to keep in mind this goal of applying core theoretical ideas in a wide variety of situations. We suggest that at the end of each chapter you try to express the key concepts as concisely as possible, repeating this exercise for the entire book near the end of your course.

MAKING CONNECTIONS

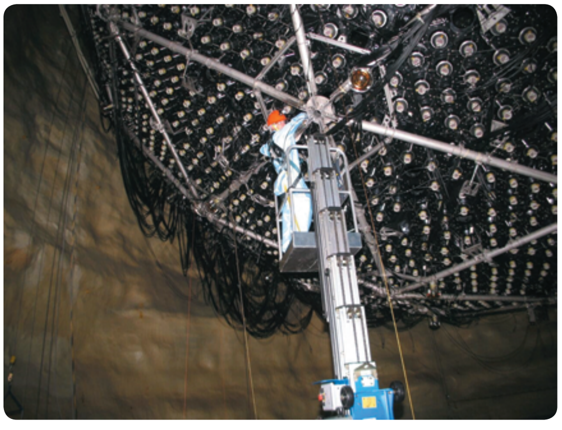
The Neutrino and the 2015 Nobel Prize

The 2015 Nobel Prize in Physics went to another Canadian scientist with deep Nova Scotia roots. Art McDonald (Figure 1-4) was born in Sydney, Nova Scotia, and, following B.Sc. and M.Sc. degrees in physics at Dalhousie University, he completed a Ph.D. at the California Institute of Technology. After positions at Chalk River, Princeton, and Queen's University, he became the director of the SNO (Sudbury Neutrino Observatory).

The Sun is powered by nuclear fusion processes deep in its core. These nuclear reactions are predicted to produce tiny, electrically uncharged particles called neutrinos (the word comes from the Italian for "little neutral one"). Neutrinos are very difficult to detect, since they pass through most objects without interaction. For example, many billions of neutrinos from the Sun pass through your fingernail every second! Later in this book (Chapters 30, 34, and 35), you will learn much more about neutrinos and nuclear reactions. The early neutrino detection measurements consistently revealed a lower number of neutrinos than predicted by nuclear models, and this was called the solar neutrino problem.

Located deep underground within a former nickel mine in Sudbury, the SNO collaboration built a sensitive detector for neutrinos (Figure 1-4). Ultimately, researchers there were able to show that the resolution of the solar neutrino problem was that neutrinos could change from one variety to another during passage from the Sun to Earth (there are three types of neutrinos, and detectors are usually sensitive only to one type).

The 2015 Nobel Prize in Physics was awarded jointly and equally to Art McDonald of SNO and to Takaaki Kajita of Japan, who had studied neutrinos produced from cosmic rays using the Super-Kamiokande neutrino detector. Together the two groups clearly showed that neutrino oscillations took place, with one type of neutrino transforming into another. This in turn implied that even though the neutrino mass is very tiny, it must not be zero.



SNOLAB

THE CANADIAN PRESS/Fred Chartrand

Figure 1-4 On left is a portion of the neutrino detector at SNO, and at right is Art McDonald, co-recipient of the 2015 Nobel Prize in Physics.

Physicists need to be creative Physicists design experiments, find applications for physical principles, and develop new models and theories. Some philosophers of science have asked whether the electron was invented or discovered. Such questioning stresses that, while there is a part of physics that is independent of the observer, the specific models we develop to help understand nature critically depend on the creativity and imagination of physicists. It is not surprising that many physicists are also interested in other creative pursuits, such as music and art.

Physics is a highly collaborative discipline Most physicists routinely work with colleagues from other countries, often using international research facilities. Pick up a physics research journal and you will see that the majority of papers are written by collaborations of scientists from different institutions and countries. For example, the ATLAS (A Toroidal LHC Apparatus) LHC (Large Hadron Collider) experiment is a collaboration of more than 3000 researchers from more than 40 different countries. The LIGO (Laser Interferometer Gravitational-Wave Observatory) scientific collaboration includes more than 1000 scientists. Because of its collaborative nature, interpersonal and leadership skills are critical for success in physics.

Physics is both deeply theoretical and highly applied Some physicists work exclusively in fundamental areas that have no immediate application, whereas others concentrate on solving applied problems. Very often work initially deemed to have little practical use turns out to have important applications. For example, in 1915, Albert Einstein published a new theory of gravitation called general relativity. When general relativity was developed, it had no foreseeable practical applications. Today, however, the Global Positioning System (GPS) would be hopelessly inaccurate without corrections for the gravitational effects predicted by general relativity theory (see Chapter 30).

Physics involves many skills Through the study of physics you can learn critical thinking, computational, and analytical skills that can be applied beyond the sciences and engineering. You will use leading-edge technologies such as 3-D models and printing, digital signal analysis, automated control systems, digital image analysis, visualization, symbolic algebra, and powerful computational software in physics, learning techniques that have broad application. For example, a number of physicists find employment developing economic and investment models for financial institutions, while others find positions in computing and technological fields, including game development, media special effects, quality control, and advanced manufacturing support.

Physics interfaces strongly with other sciences The study of physics is increasingly interdisciplinary, with many physicists working in areas that span physics and other disciplines, for example, medical physics, biophysics, chemical physics, materials science, geophysics, or physical environmental science. Also, many scientists in other fields use physics as part of their everyday work.

Successful physicists are good communicators Whether writing experiment reports, scientific papers, or grant applications, or communicating with classes or the general public, scientists must have effective and flexible communication skills. You will probably be surprised at how much of your time as a physicist is spent in some form of communication, and also at the breadth of audiences you will serve. For example, in a typical month you may find yourself presenting to a policy institute, speaking at a local school, presenting at a scientific conference, and providing comment to reporters on a scientific development. Indeed, a number of physicists are well-known communicators of science, people such as Brian Cox, Brian Greene, Michio Kaku, Lawrence Krauss, Lisa Randall, and Neil deGrasse Tyson.

In this textbook, we provide a way for you to check your understanding of key concepts, relationships, and techniques. Each section of every chapter will have at least one checkpoint, the first of which (on the nature of physics) follows. You should test your understanding before reading further and then check your answer with the upside-down response at the bottom of the checkpoint. Physics is a highly sequential subject, and mastery of one concept is often needed to understand the next concept.

CHECKPOINT 1-1

What Is Physics?

Which of the following activities most accurately describes the realm of physics?

(a) Making conjectures about the universe that can be neither proved nor disproved
(b) Proposing and testing physical models by collecting experimental data
(c) Suggesting a theory that is only applicable to interacting galaxies
(d) Defining virtual environment properties in a game environment

ANSWER: (b) is the best answer, incorporating aspects of data collection, models, prediction, and testing. The realm of physics is concerned with matters that can, at least potentially, be proved or disproved. Therefore, the first answer is eliminated. While physicists certainly study galaxy interactions, a theory that only applies to one part of the universe would not be physics, where we seek relationships with broad application. A physics background would be useful for those developing virtual environments for games, but the work itself is not physics.