SERWAY JEWETT WILSON WILSON ROWLANDS

PHYSICS

FOR GLOBAL SCIENTISTS AND ENGINEERS

VOLUME 2

2ND EDITION

Some physical constants

Quantity	**Symbol**	**Value**[a]
Atomic mass unit	u	1.660 538 782 (83) × 10^{-27} kg 931.494 028 (23) MeV/c^2
Avogadro's number	N_A	6.022 141 79 (30) × 10^{23} particles/mol
Bohr magneton	$\mu_B = \dfrac{e\hbar}{2m_e}$	9.274 009 15 (23) × 10^{-24} J/T
Bohr radius	$a_0 = \dfrac{\hbar^2}{m_e e^2 k_e}$	5.291 772 085 9 (36) × 10^{-11} m
Boltzmann's constant	$k_B = \dfrac{R}{N_A}$	1.380 650 4 (24) × 10^{-23} J/K
Compton wavelength	$\lambda_C = \dfrac{h}{m_e c}$	2.426 310 217 5 (33) × 10^{-12} m
Coulomb constant	$k_e = \dfrac{1}{4\pi\epsilon_0}$	8.987 551 788 . . . × 10^{9} N•m²/C² (exact)
Deuteron mass	m_d	3.343 583 20 (17) × 10^{-27} kg 2.013 553 212 724 (78) u
Electron mass	m_e	9.109 382 15 (45) × 10^{-31} kg 5.485 799 094 3 (23) × 10^{-4} u 0.510 998 910 (13) MeV/c^2
Electron volt	eV	1.602 176 487 (40) × 10^{-19} J
Elementary charge	e	1.602 176 487 (40) × 10^{-19} C
Gas constant	R	8.314 472 (15) J/mol•K
Gravitational constant	G	6.674 28 (67) × 10^{-11} N•m²/kg²
Neutron mass	m_n	1.674 927 211 (84) × 10^{-27} kg 1.008 664 915 97 (43) u 939.565 346 (23) MeV/c^2
Nuclear magneton	$\mu_n = \dfrac{e\hbar}{2m_p}$	5.050 783 24 (13) × 10^{-27} J/T
Permeability of free space	μ_0	$4\pi \times 10^{-7}$ T•m/A (exact)
Permittivity of free space	$\epsilon_0 = \dfrac{1}{\mu_0 c^2}$	8.854 187 817 . . . × 10^{-12} C²/N•m² (exact)
Planck's constant	h	6.626 068 96 (33) × 10^{-34} J•s
	$\hbar = \dfrac{h}{2\pi}$	1.054 571 628 (53) × 10^{-34} J•s
Proton mass	m_p	1.672 621 637 (83) × 10^{-27} kg 1.007 276 466 77 (10) u 938.272 013 (23) MeV/c^2
Rydberg constant	R_H	1.097 373 156 852 7 (73) × 10^{7} m^{-1}
Speed of light in vacuum	c	2.997 924 58 ×10^{8} m/s (exact)

Note: These constants are the values recommended in 2006 by CODATA, based on a least-squares adjustment of data from different measurements. For a more complete list, see P. J. Mohr, B. N. Taylor, and D. B. Newell, CODATA Recommended Values of the Fundamental Physical Constants: 2006. *Rev. Mod. Phys.* **80**(2), 633–730, 2008.

[a] The numbers in parentheses for the values represent the uncertainties of the last two digits.

Solar system data

Body	Mass (kg)	Mean radius (m)	Period (s)	Mean distance from the Sun (m)
Mercury	3.30×10^{23}	2.44×10^{6}	7.60×10^{6}	5.79×10^{10}
Venus	4.87×10^{24}	6.05×10^{6}	1.94×10^{7}	1.08×10^{11}
Earth	5.97×10^{24}	6.37×10^{6}	3.156×10^{7}	1.496×10^{11}
Mars	6.42×10^{23}	3.39×10^{6}	5.94×10^{7}	2.28×10^{11}
Jupiter	1.90×10^{27}	6.99×10^{7}	3.74×10^{8}	7.78×10^{11}
Saturn	5.68×10^{26}	5.82×10^{7}	9.29×10^{8}	1.43×10^{12}
Uranus	8.68×10^{25}	2.54×10^{7}	2.65×10^{9}	2.87×10^{12}
Neptune	1.02×10^{26}	2.46×10^{7}	5.18×10^{9}	4.50×10^{12}
Pluto[a]	1.25×10^{22}	1.20×10^{6}	7.82×10^{9}	5.91×10^{12}
Moon	7.35×10^{22}	1.74×10^{6}	—	—
Sun	1.989×10^{30}	6.96×10^{8}	—	—

[a] In August 2006, the International Astronomical Union adopted a definition of a planet that separates Pluto from the other eight planets. Pluto is now defined as a 'dwarf planet' (like the asteroid Ceres).

Physical data often used

Average Earth–Moon distance	3.84×10^{8} m
Average Earth–Sun distance	1.496×10^{11} m
Average radius of the Earth	6.37×10^{6} m
Density of air (20°C and 1 atm)	1.20 kg/m^3
Density of air (0°C and 1 atm)	1.29 kg/m^3
Density of water (20°C and 1 atm)	1.00×10^{3} kg/m^3
Free-fall acceleration	9.80 m/s^2
Mass of the Earth	5.97×10^{24} kg
Mass of the Moon	7.35×10^{22} kg
Mass of the Sun	1.99×10^{30} kg
Standard atmospheric pressure	1.013×10^{5} Pa

Note: These values are the ones used in the text.

Some prefixes for powers of ten

Power	Prefix	Abbreviation	Power	Prefix	Abbreviation
10^{-24}	yocto	y	10^{1}	deka	da
10^{-21}	zepto	z	10^{2}	hecto	h
10^{-18}	atto	a	10^{3}	kilo	k
10^{-15}	femto	f	10^{6}	mega	M
10^{-12}	pico	p	10^{9}	giga	G
10^{-9}	nano	n	10^{12}	tera	T
10^{-6}	micro	μ	10^{15}	peta	P
10^{-3}	milli	M	10^{18}	exa	E
10^{-2}	centi	c	10^{21}	zetta	Z
10^{-1}	deci	d	10^{24}	yotta	Y

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PHYSICS

FOR GLOBAL SCIENTISTS AND ENGINEERS

VOLUME 2

2ND EDITION

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2nd Edition
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Preface

This second edition of *Physics for global scientists and engineers* is an adaptation of the classic text *Physics for scientists and engineers* by Serway and Jewett to better suit students and instructors outside of the US. The language used has been modified, examples and case studies from local regions have been included, and quantities are given in SI units rather than imperial, except where a unit conversion is part of the learning objective for the problem. Uncertainty analysis is an integrated part of the text, in keeping with the empirical nature of the subject, and to help support students' learning in laboratories and reduce the 'disconnect' that sometimes occurs between the laboratory component of a course and the lecture/tutorial components. We have retained the excellent features of the original text, such as Pitfall Preventions and the selection of Quick Quizzes, conceptual and quantitative questions, as well as pedagogical features such as the *Try this* experiments.

The sequence of content reflects the ongoing development of physics. Rather than dividing the content into classical and modern, with the modern physics section largely consisting of discoveries and theories now about 100 years old, we instead divide the material by topic. Hence, we include the material on relativity in the first section on mechanics, where it is integrated with Newtonian mechanics that gives students an early introduction into what many find to be one of the more exciting aspects of physics. This arrangement also allows a stronger focus on quantum physics as the unifying theory that describes the physics of atoms, molecules and nuclei in the final chapters.

Objectives

This introductory physics textbook has two main objectives: to provide the student with a clear and logical presentation of the basic concepts and principles of physics and to strengthen an understanding of the concepts and principles through a broad range of interesting real-world applications. To meet these objectives, we emphasise sound physical arguments and problem-solving methodology. At the same time, we attempt to motivate the student through case studies and practical examples that demonstrate the role of physics in other disciplines, including engineering, chemistry, biology and medicine.

Changes from the ninth edition of Serway and Jewett's *Physics for scientists and engineers* and an overview of the second edition

A number of changes and improvements were made for the first edition of this text and these have been built upon for this second edition. The new features are based on our experiences and on current trends in science education. Other changes were incorporated in response to comments and suggestions offered by reviewers of the manuscript and our colleagues.

Line-by-line revision of the examples, questions and problems set. Each example, question and problem has been reviewed and many have been revised, to improve both readability and appeal to an international student cohort. Except in a few cases where a unit conversion is a deliberate element of a problem, all quantities are given in SI units. We have made careful revisions to worked examples so that the use of *Analysis models* and *Problem-solving strategies* are made more explicit and followed more consistently. The use of diagrams of various sorts to represent the situation, and as a first step in understanding the physical situation, is used in all but very simple mathematical problems. Solutions are presented symbolically as far as possible, and dimension checking is performed *before* numbers are substituted at the end. This approach helps students to think symbolically when they solve problems, and to check that their analysis is at least plausible instead of automatically looking to insert numbers into an equation to solve a problem.

Changes to and re-ordering of content. For the first edition, the material on relativity was placed in the mechanics section, giving students an early introduction to an area of physics that many find exciting and that is comparatively modern. A new chapter on the mechanical properties of solids was added, and the material on mechanical properties of fluids was expanded into two chapters including both static and dynamic properties. These chapters are grouped together in Part 2, where they follow logically from the mechanics introduced in Part 1. The section on X-ray diffraction was expanded, as this is a significant technique in analysis of materials, and is one often encountered in undergraduate teaching laboratories. Part 7, on Quantum Physics, groups together our treatment of all those physical systems that are described by quantum, rather than classical, mechanics.

For this second edition, Chapter 4, which describes Newton's laws, has been substantially revised based on recent physics education research. The concepts of 'weight' and 'apparent weight' are now dealt with far more explicitly and the language used to describe these concepts is discussed in detail. The section on Newton's third law has been expanded, and is now applied more explicitly in worked examples.

The problem solving strategy has been updated for this edition to reflect best practice in pedagogy. The second step, previously 'Categorise', has been replaced with 'Model', which asks students to consider what assumptions and approximations they can make, and what existing models they can apply. This better reflects problem solving strategies used by experts.

Integration of uncertainties. Uncertainty, or the degree to which you can be confident in a measurement or other experimental result, is a critical part of any empirical science. An understanding of the role of uncertainty is perhaps most important in physics, which relies on quantitative measurements to develop and test mathematically expressed theories and laws. Physics courses generally include a laboratory component in which students meet uncertainties, but they are generally missing from other contexts such as lectures, textbooks and homework problems. Because of this, students may have little practice at uncertainty analysis, and may see it as something that only ever needs to be considered in the lab. The new edition integrates uncertainty analysis into the text, beginning with a section in Chapter 1 on 'Uncertainties in Measurement' contributed by Associate Professor Les Kirkup, followed by the inclusion of uncertainties in at least one worked example per chapter and several end-of-chapter problems. In these examples and problems the uncertainty analysis is an integral part of the problem, and a range of techniques for calculating the final uncertainty are demonstrated. The number of significant figures shown in the final answer depends upon the uncertainty, rather than being fixed. In some examples and problems the uncertainties are expressed as tolerances, for example for electronic components, as is typical in engineering.

Focus questions. Each chapter begins with a question designed to engage the interest of the student in the material within the chapter. These questions use a range of contexts including historical, such as the discovery of the shape of the DNA molecule and the use of bubble chambers; everyday, such as rainbows and colour-travel paint on cars; and technological examples, such as solar panels, lasers and reinforced concrete. These questions are answered at the end of the chapter, drawing together ideas from within the chapter into an answer and an explanation.

'Try this' examples. Each chapter includes *Try this* examples in which students are instructed to perform a simple experiment, using everyday items they are likely to have at hand in an office or kitchen, and to observe and explain the results. Research has shown that when students are actively engaged, particularly by 'doing' as well as thinking, deeper learning is likely to result.

Case studies highlighting interesting and significant local and international research. This new edition contains nine case studies, four of which are new, written by scientists, including physiologists, chemists, biologists and physicists as well as engineers, from around the world. The case studies highlight the application of physics to disciplines such as ergonomics (ergonomics of sheep shearing) and medicine (fibre optics and the human body) and important developments such as the discovery of the Higgs boson. A number of additional case studies can be found online.

Expansion of the analysis model approach. The analysis model approach used in the previous edition is used in this version of *Physics* and is expanded to include dimension checking as an explicit step in problem solving. It lays out a standard set of situations that appear in most physics problems. These situations are based on four simplification models: particle, system, rigid object and wave. The student thinks about what the entity is doing and how it interacts with its environment and what assumptions and approximations can reasonably be made. This leads the student to identify a particular analysis model for the problem. As the student gains more experience, he or she will lean less on the analysis model approach and begin to identify fundamental principles directly, more like a physicist does. This approach is further reinforced in the end-of-chapter summary under the heading *Analysis models for problem solving.*

Content

The material in this book provides an introduction to physics at a level appropriate for first year calculus-based university physics courses. It will also be a useful reference for students continuing their physics studies beyond first year. The book is divided into seven parts. Part 1 (Chapters 1 to 12) deals with the fundamentals of Newtonian mechanics and introduces students to relativity; Part 2 (Chapters 13 to 15) introduces the mechanical properties of fluids and solids; Part 3 (Chapters 16 to 18) covers oscillations, mechanical waves and sound; Part 4 (Chapters 19 to 22) addresses heat and thermodynamics; Part 5 (Chapters 23 to 34) treats electricity and magnetism; Part 6 (Chapters 35 to 38) covers light and optics; and Part 7 (Chapters 39 to 44) introduces the concepts of quantum mechanics needed to describe the physics of atoms, molecules and nuclei.

Helpful features

Pedagogical use of colour. Readers should consult the **pedagogical colour chart** (inside the front cover) for a listing of the colour-coded symbols used in the text diagrams. This system is followed consistently throughout the text.

Use of calculus. We have introduced calculus gradually, keeping in mind that students often take introductory courses in calculus and physics concurrently. Most steps are shown when basic equations are developed, and reference is often made to mathematical appendices.

Appendices and endpapers. Several appendices are provided. Most of the appendix material represents a review of mathematical concepts and techniques used in the text, including scientific notation, algebra, geometry, trigonometry, vector algebra and calculus. Reference to these appendices is made throughout the text, and where this is done an icon appears in the margin to highlight the link. In addition to the mathematical reviews, the appendices contain tables of physical data, conversion factors, and the SI units of physical quantities as well as a periodic table of the elements. Other useful information – fundamental constants and physical data, planetary data, a list of standard prefixes, mathematical symbols, the Greek alphabet, and standard abbreviations are given on the endpapers for quick access.

About the authors

Raymond A. Serway received his doctorate at Illinois Institute of Technology and is Professor Emeritus at James Madison University. In 2011, he was awarded with an honorary doctorate degree from his alma mater, Utica College. He received the 1990 Madison Scholar Award at James Madison University, where he taught for 17 years. Dr Serway began his teaching career at Clarkson University, where he conducted research and taught from 1967 to 1980. He was the recipient of the Distinguished Teaching Award at Clarkson University in 1977 and the Alumni Achievement Award from Utica College in 1985. As Guest Scientist at the IBM Research Laboratory in Zurich, Switzerland, he worked with K. Alex Müller, 1987 Nobel Prize recipient. Dr Serway also was a visiting scientist at Argonne National Laboratory, where he collaborated with his mentor and friend, the late Dr Sam Marshall. Dr Serway is the co-author of *College Physics,* Ninth Edition; *Principles of Physics,* Fifth Edition; *Essentials of College Physics; Modern Physics,* Third Edition; and the high school textbook *Physics,* published by Holt McDougal. In addition, Dr Serway has published more than 40 research papers in the field of condensed matter physics and has given more than 60 presentations at professional meetings. Dr Serway and his wife, Elizabeth, enjoy traveling, playing golf, fishing, gardening, singing in the church choir, and especially spending quality time with their four children, ten grandchildren, and a recent great grandson.

John W. Jewett, Jr. earned his undergraduate degree in physics at Drexel University and his doctorate at Ohio State University, specialising in optical and magnetic properties of condensed matter. Dr Jewett began his academic career at Richard Stockton College of New Jersey, where he taught from 1974 to 1984. He is currently Emeritus Professor of Physics at California State Polytechnic University, Pomona. Through his teaching career, Dr Jewett has been active in promoting effective physics education. In addition to receiving four National Science Foundation grants in physics education, he helped found and direct the Southern California Area Modern Physics Institute (SCAMPI) and Science IMPACT (Institute for Modern Pedagogy and Creative Teaching). Dr Jewett's honours include the Stockton Merit Award at Richard Stockton College in 1980, selection as Outstanding Professor at California State Polytechnic University for 1991–92, and the Excellence in Undergraduate Physics Teaching Award from the American Association of Physics Teachers (AAPT) in 1998. In 2010, he received an Alumni Lifetime Achievement Award from Drexel University in recognition of his contributions in physics education. He has given more than 100 presentations both domestically and abroad, including multiple presentations at national meetings of the AAPT. He has also published 25 research papers in condensed matter physics and physics education research. Dr Jewett is the author of *The World of Physics: Mysteries, Magic, and Myth,* which provides many connections between physics and everyday experiences. In addition to his work as the co-author for *Physics for Scientists and Engineers,* he is also the co-author on *Principles of Physics,* Fifth Edition, as well as *Global Issues,* a four-volume set of instruction manuals in integrated science for high school. Dr Jewett enjoys playing keyboard with his all-physicist band, travelling, underwater photography, learning foreign languages, and collecting antique quack medical devices that can be used as demonstration apparatus in physics lectures. Most importantly, he relishes spending time with his wife, Lisa, and their children and grandchildren.

Kate Wilson has a PhD in computational physics from Monash University and a Graduate Diploma in Secondary Teaching from the University of Canberra. She is a senior lecturer at UNSW Canberra (UNSW@ADFA) in the School of Engineering and Information Technology where she teaches in Civil Engineering, and is a member of the Learning and Teaching Group where she teaches the Graduate Teaching Program. Kate has been a member of the Sydney University Physics Education Research group, an Innovative Teaching and Educational Technology Fellow at the University of New South Wales, first year coordinator in physics at the Australian National University and director of the Australian Science Olympiads Physics Program. She has taught physics from first year algebra-based courses to third year condensed matter physics. She has published research on neural networks, magnetism, ballast water pumping and physics education. Her recent research looks at students' understanding of Newtonian mechanics, and this book is informed by that research. She is an author of the resource set 'Workshop Tutorials for Physics' and 'Nelson Physics for the Australian Curriculum Units 1 & 2' and 'Nelson Physics for the Australian Curriculum Units 3 & 4'.

Anna Wilson has a BSc(Hons) from the University of Bristol and obtained a PhD in nuclear physics from the University of Liverpool. She also has a Master of Higher Education from the Australian National University. She has worked at universities in the UK, the US, France and Australia. She has taught physics at all levels of the undergraduate degree, including algebra-based first year courses, quantum mechanics, and nuclear and particle physics, and is the recipient of teaching awards including an Australian Learning and Teaching Council Citation for Outstanding Contribution to Student Learning and an Award for Teaching Excellence. She has published research in the fields of optics, nuclear structure physics and higher education. While working on this book, Anna divided her time between the University of Canberra's Teaching and Learning Centre and the Research School of Physics and Engineering at the Australian National University. She is currently undertaking a second PhD in Education at the University of Stirling, UK.

Wayne Rowlands is a Senior Lecturer in the Department of Physics and Astronomy at Swinburne University of Technology. He has a PhD in laser atomic physics from the University of Melbourne, and a Graduate Certificate in Learning and Teaching from Swinburne University of Technology. His interests cover fundamental experimental research, science education and outreach. Wayne was a Chief Investigator in the ARC Centre of Excellence for Quantum-Atom Optics, with a particular interest in Bose-Einstein condensation. He is an active member of the Engineering and Science Education Research Group at Swinburne, has presented at education research conferences, and was invited to deliver the Australian Institute of Physics 'Youth Lecture' series of talks by the Victorian Branch (in 2002) and the Queensland Branch (in 2006). Wayne has been the editor of 'AOS News', the journal of the Australian Optical Society, and also served as a long-term presenter on the 3RRR radio science show 'Einstein A Go Go'.

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We greatly appreciate the case study authors, listed below, for their contribution not only in explaining their work at an appropriate level and in an engaging way, but for collaborating with us in ensuring that each case study was integrated well into the text.

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- Case study 3: Elizabeth Angstmann
- Case study 4: Nicoleta Gacieu
- Case study 5: David Low
- Case study 6: Jeff Tallon
- Case study 7: Stephan Winkler
- Case study 8: John Love
- Case study 9: Geoffrey Taylor

We would like to thank the case study authors from the previous edition, which can now be found online:

- Online Case Study 1: Chiara Neto
- Online Case Study 2: Joe Wolfe
- Online Case Study 3: Mark Boland
- Online Case Study 4: Tony Irwin

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To the student

How to study

The most effective way to learn physics, or any other subject, is to be as active in your learning as possible.

Before going to lectures, read any notes provided in advance and any relevant sections of the text book. **During** lectures, pay attention and try to fit what is being discussed in lectures into your existing understanding and knowledge. Identify anything that doesn't seem to fit, and ask questions. If there are questions or activities in lectures, participate. **After** lectures, do any assigned homework problems, and review your understanding of the lecture content. Use resources including the textbook to help you. Work through example problems, don't just read them. Do the *Try this* examples – and try to predict what will happen before you do the experiment. When you try to explain what you observed, pay particular attention to any mismatch between your predictions and observations. Use other resources, such as websites, other books, articles and other students.

Find colleagues to study with. Sometimes an explanation from a friend will be easier to understand than one from a lecturer or tutor. Explaining things yourself to colleagues is also a great way to learn because it forces you to put into clear terms what you know, and can help you identify when you don't really understand a concept or principle as well as you thought you did. Anyone who has taught will tell you that teaching a subject is the best way to learn it yourself.

Participate in tutorials and laboratory classes. Ask lots of questions, think about what you are doing, and *ask yourself* lots of questions to make sure you understand. Use the opportunities to interact with teaching staff and other students. To really learn how to do something, you need to practice doing it – this is what laboratory and tutorial classes are for – for you to apply what you have learnt in lectures and from other resources and *do* some physics.

Use this book. Don't just read it, **do** the examples, problems, quiz questions and *Try this* experiments. We have tried to provide lots of opportunities for you to practice using the concepts and principles. When you do read, think about what you are reading, make notes of anything that you don't understand and ask questions of your lecturers and tutors, and other students. Often you will need to read a section more than once so that you understand it, especially when it is material that is new to you.

Work through the examples yourself, without looking at the solutions, then check your solution. Make sure you think carefully about any differences in your solution and the one given. Have you made a mistake? Have you made different simplifying assumptions? Follow the general problem-solving strategy, particularly ensuring that you understand the physical situation and which concepts and principles can be applied *before* you look to any equations. When you have found a solution, check that it is dimensionally correct and physically sensible. This is a good habit to get into, and will serve you well in exams. Few things annoy a marker more than dimensionally incorrect answers (or answers with missing units), or answers that are physically silly. Each chapter has many problems for you to practice on, as well as conceptual questions that will help you apply the concepts and principles covered in the chapter. It is important to be able to apply them without always resorting to an equation. Answers to *Quick quizzes* are given at the end of the textbook, and solutions to selected end-of-chapter questions and problems are provided in the accompanied *Student Solutions Manual.*

Do the *Try this* experiments. They have been designed to use only simple equipment that you can find in an office or kitchen, with very few exceptions. Use a *predict – observe – explain* strategy. Think about what you expect to happen before you do the experiment, based on your existing knowledge. Observe carefully what does happen, and repeat the experiment if necessary. Ask anyone else who is working with you to also observe, or to do the experiment while you watch. Then explain your observations, comparing them with your initial predictions. Was your prediction correct, and if not, why not? Think about similar situations you may have observed that can be explained by the same principles.

Use the online resources. Use the online tutorial material and Enhanced WebAssign content. Work through the tutorials, and use the Active Figures. Use a *predict – observe – explain* strategy with the Active Figures.

Set up a regular study schedule, and spend some time at least a few times each week on your study, making it as active as possible – doing, not just reading. Do not wait until just before the exam and then try to 'cram' a semester's worth of material.

Finally, and most importantly, think! Focus on understanding and applying the concepts and principles, rather than memorising equations.

We wish you great enjoyment and success in your studies.

Kate Wilson, Anna Wilson and Wayne Rowlands

Guide to the text

As you read this text you will find a number of features in every chapter to enhance your study of physics and help you understand how the theory is applied in the real world.

PART OPENING FEATURES

Mechanics

PART 1

A rocket is launched. To understand how the rocket moves we need to think about how it responds to the forces that act on it, including gravity and air resistance. We need to understand how these forces change as the rocket moves. We apply conservation principles, including conservation of momentum, to help us model the behaviour of the rocket. These topics, and others, are covered in Part 1: Mechanics.

Shutterstock.com/James and Bonnie Grower

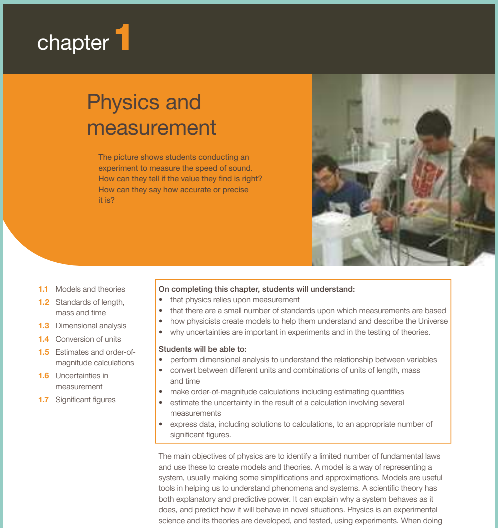
Physics, the most fundamental physical science, is concerned with the fundamental principles of the Universe. It is the foundation upon which the other sciences – astronomy, biology, chemistry and geology – are based. The beauty of physics lies in the simplicity and universal applicability of its fundamental principles and in the manner in which just a small number of concepts and models can enrich and expand our view of the world around us.

We begin with *classical mechanics*, in which we shall meet fundamental principles such as conservation of energy and momentum, and begin to understand the forces that shape the world around us. We shall use these principles and concepts again and again in our study of other topics in physics, including *properties of matter*, *thermodynamics*, *waves*, *electromagnetism*, *optics*, and *quantum and nuclear physics*. To understand what is happening in the picture of the rocket we need to use ideas from all these topics: mechanics to understand the path taken by the rocket, thermodynamics to understand the expansion of the fuel on ignition, waves and electromagnetism to understand how the light reaches the camera, and optics to understand how the photo is taken.

We start our study of mechanics by using *kinematics* to describe the motion of objects, and finish this section with a brief look at *special relativity*, which describes the behaviour of objects moving at very high speeds. We will introduce several analysis models for solving problems. The first two case studies, looking at applications of the physics described in these chapters, are introduced. The first case study, which looks at forces on the human body when shearing sheep, is an application of the basic principles of mechanics to solve a problem in ergonomics. The second case study looks at satellite navigation systems, gravity and relativity. The basic concepts you will learn in these chapters are applicable to many different systems, and are used by physicists, engineers, physiotherapists and people in many other professions.

The part opener introduces the branch of physics to be covered in the following chapters, providing an overview of how the chapters relate to each other. Each part opener has a **vignette** that includes a real-world scenario and visual, providing context to the concepts to be covered.

CHAPTER OPENING FEATURES



chapter 1

Physics and measurement

The picture shows students conducting an experiment to measure the speed of sound. How can they tell if the value they find is right? How can they say how accurate or precise it is?

1.1 Models and theories
1.2 Standards of length, mass and time
1.3 Dimensional analysis
1.4 Conversion of units
1.5 Estimates and order-of-magnitude calculations
1.6 Uncertainties in measurement
1.7 Significant figures

On completing this chapter, students will understand:
- that physics relies upon measurement
- that there are a small number of standards upon which measurements are based
- how physicists create models to help them understand and describe the Universe
- why uncertainties are important in experiments and in the testing of theories.

Students will be able to:
- perform dimensional analysis to understand the relationship between variables
- convert between different units and combinations of units of length, mass and time
- make order-of-magnitude calculations including estimating quantities
- estimate the uncertainty in the result of a calculation involving several measurements
- express data, including solutions to calculations, to an appropriate number of significant figures.

The main objectives of physics are to identify a limited number of fundamental laws and use these to create models and theories. A model is a way of representing a system, usually making some simplifications and approximations. Models are useful tools in helping us to understand phenomena and systems. A scientific theory has both explanatory and predictive power. It can explain why a system behaves as it does, and predict how it will behave in novel situations. Physics is an experimental science and its theories are developed, and tested, using experiments. When doing experiments or making observations we use standards of measurement, and we describe our results using units that other scientists recognise. We use uncertainties on measurements to indicate the precision of the measurements. There may be more than one theory to account for an observed phenomenon, and measurements allow us to test our theories.

ENHANCED WebAssign

The problems found in this chapter may be assigned online in Enhanced Web Assign.

Gain an insight into how physics theories relate to the real world through the **chapter opening vignette** with focus questions at the beginning of each chapter. The vignette is then revisited at the end of each chapter.

The **learning objectives** give you a clear sense of the topics covered in each chapter and what you should be able to do after reading the chapter.

FEATURES WITHIN CHAPTERS

Key Equations

$$\Delta\theta \equiv \theta_f - \theta_i$$ ◄ Angular displacement

The rate at which this angular displacement occurs can be quantified by defining the **average angular speed** ω_{avg} (Greek letter omega) as the ratio of the angular displacement of a rigid object to the time interval Δt during which the displacement occurs:

$$\omega_{avg} \equiv \frac{\theta_f - \theta_i}{t_f - t_i} = \frac{\Delta\theta}{\Delta t} \qquad (9.2)$$ ◄ Average angular speed

In analogy to translational speed, the **instantaneous angular speed** ω is defined as the limit of the average angular speed as Δt approaches zero:

$$\omega \equiv \lim_{\Delta t \to 0} \frac{\Delta\theta}{\Delta t} = \frac{d\theta}{dt} \qquad (9.3)$$ ◄ Instantaneous angular speed

Key equations, **concepts** and **laws** are highlighted to help you identify important information.

Key equations are also numbered for easy reference.

Quick **Quiz**

Quick Quiz 5.5

Imagine the person shown in Figure 5.24 is holding a ball in their hand. They gently let go of the ball (not throw it) when they are at the position shown in Figure 5.24. What is the path of the ball as seen by this person? (a) It stays where they released it, floating next to their hand. (b) It falls to land approximately at their feet. (c) It falls to land behind them, approximately where their feet were when they released it. Hint: look at Figure 4.24 and draw a similar pair of diagrams for this situation.

Test your progress through each section by answering the **Quick Quiz** questions as you progress through the chapter.

Pitfall Prevention

Pitfall Prevention boxes give tips to help you avoid common physics mistakes and misconceptions.

Pitfall Prevention 9.1

The radian is an unusual unit. An angle expressed in radians is a pure number. It is a ratio of two lengths, so it is dimensionless. In rotational equations, you *must* use angles expressed in radians. Don't fall into the trap of using angles measured in degrees in rotational equations. Be careful how you use your calculator – make sure you know what units *it* is working in!

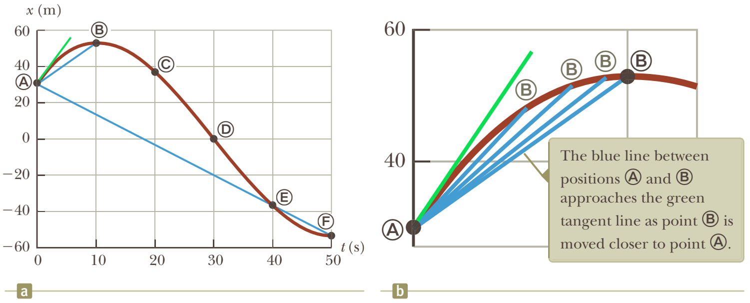
TRY THIS

TRY THIS

Stand next to one friend (A) and get two friends (B and C) to stand next to each other facing you, so they are the same distance from you and the person (A) standing next to you. You and your friend (A) throw a ball to the person (B or C) opposite you at exactly the same time, so they can catch them. The balls must travel the same horizontal distance, but you can throw them with different maximum heights. Does the ball with the higher or lower maximum height reach the person it is thrown to first? Does this happen every time?

Try this boxes provide examples of simple experiments using everyday items that you can easily try at home.

Active figures

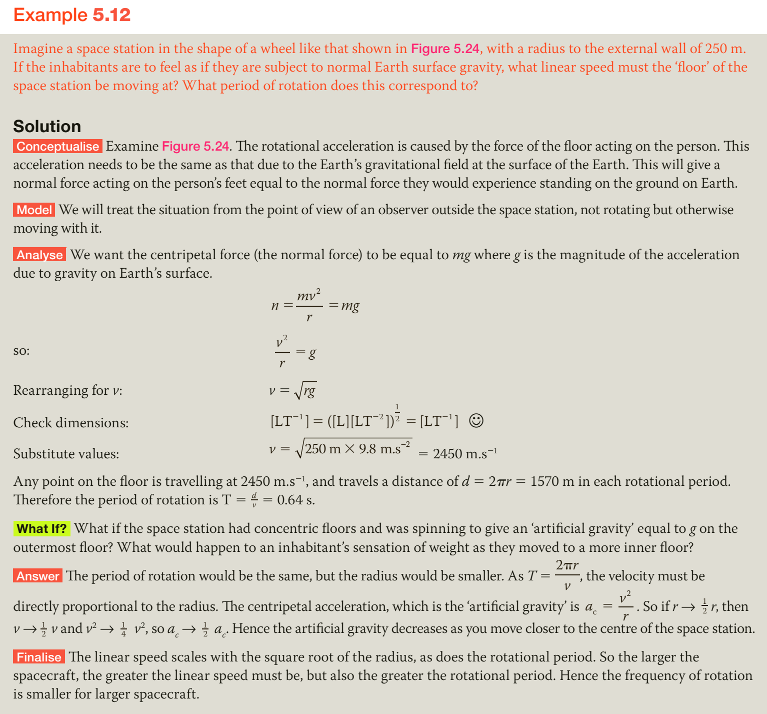


The blue line between positions Ⓐ and Ⓑ approaches the green tangent line as point Ⓑ is moved closer to point Ⓐ.

Active Figure 2.3 (a) Graph representing the motion of the car in Active Figure 2.1. (b) An enlargement of the upper-left-hand corner of the graph.

Active Figures indicate concepts that are supported by interactive animated presentations in the Physics companion website.

Worked Example



Example 5.12

Imagine a space station in the shape of a wheel like that shown in Figure 5.24, with a radius to the external wall of 250 m. If the inhabitants are to feel as if they are subject to normal Earth surface gravity, what linear speed must the 'floor' of the space station be moving at? What period of rotation does this correspond to?

Solution

Conceptualise Examine Figure 5.24. The rotational acceleration is caused by the force of the floor acting on the person. This acceleration needs to be the same as that due to the Earth's gravitational field at the surface of the Earth. This will give a normal force acting on the person's feet equal to the normal force they would experience standing on the ground on Earth.

Model We will treat the situation from the point of view of an observer outside the space station, not rotating but otherwise moving with it.

Analyse We want the centripetal force (the normal force) to be equal to *mg* where *g* is the magnitude of the acceleration due to gravity on Earth's surface.

$$n = \frac{mv^2}{r} = mg$$

so:

$$\frac{v^2}{r} = g$$

Rearranging for v:

$$v = \sqrt{rg}$$

Check dimensions:

$$[\mathrm{LT}^{-1}] = ([\mathrm{L}][\mathrm{LT}^{-2}])^{\frac{1}{2}} = [\mathrm{LT}^{-1}] \quad ☺$$

Substitute values:

$$v = \sqrt{250\ \mathrm{m} \times 9.8\ \mathrm{m.s}^{-2}} = 2450\ \mathrm{m.s}^{-1}$$

Any point on the floor is travelling at 2450 $\mathrm{m.s}^{-1}$, and travels a distance of $d = 2\pi r = 1570$ m in each rotational period. Therefore the period of rotation is $\mathrm{T} = \frac{d}{v} = 0.64$ s.

What If? What if the space station had concentric floors and was spinning to give an 'artificial gravity' equal to *g* on the outermost floor? What would happen to an inhabitant's sensation of weight as they moved to a more inner floor?

Answer The period of rotation would be the same, but the radius would be smaller. As $T = \frac{2\pi r}{v}$, the velocity must be directly proportional to the radius. The centripetal acceleration, which is the 'artificial gravity' is $a_c = \frac{v^2}{r}$. So if $r \rightarrow \frac{1}{2} r$, then $v \rightarrow \frac{1}{2} v$ and $v^2 \rightarrow \frac{1}{4} v^2$, so $a_c \rightarrow \frac{1}{2} a_c$. Hence the artificial gravity decreases as you move closer to the centre of the space station.

Finalise The linear speed scales with the square root of the radius, as does the rotational period. So the larger the spacecraft, the greater the linear speed must be, but also the greater the rotational period. Hence the frequency of rotation is smaller for larger spacecraft.

Worked Examples provide conceptual explanations along with the calculations for every step. The examples closely follow the authors' proven **General Problem Solving Strategy**, which is introduced in Chapter 2 to reinforce good problem solving habits. About one-third of the worked examples include **What If?** extensions, which further strengthens conceptual understanding.

ICONS

Wherever you see the **Go online!** icon you will find additional relevant material, including Active Figures, on the book's website at http://www.cengagebrain.com.

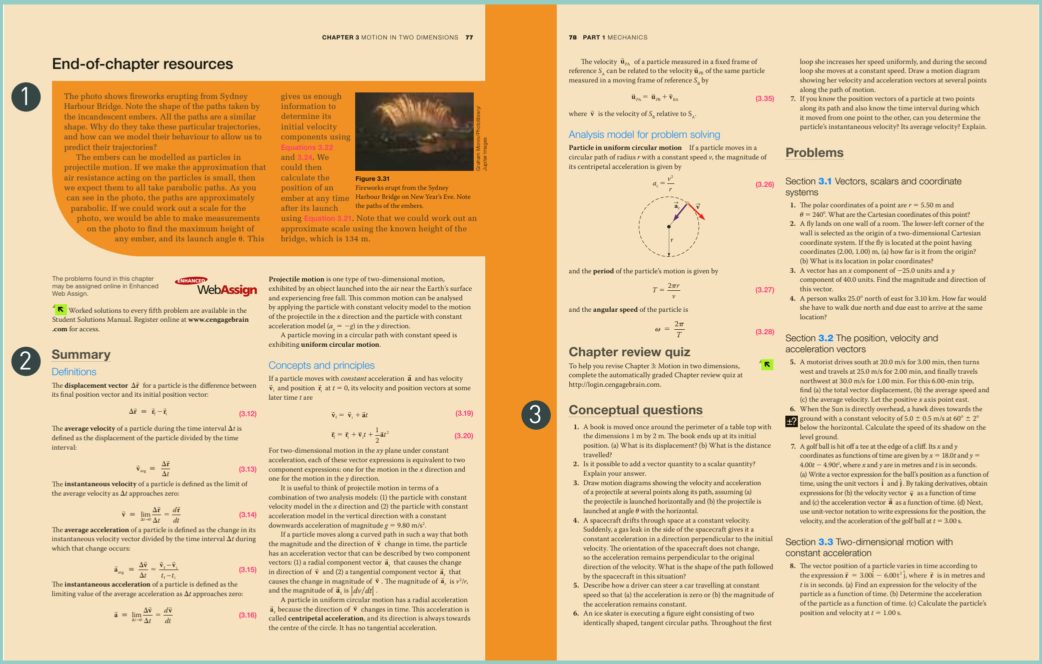
The **Uncertainty** icon highlights coverage of uncertainty, which is integrated throughout the book to help you understand this important concept in context.

NEW

The NEW **Maths icon** highlights mathematical concepts that are covered in Appendix B, directing you to the relevant content in the appendix for revision.

END-OF-CHAPTER FEATURES

At the end of each chapter you'll find several tools to help you to review, practise and extend your knowledge of the key learning objectives.



CHAPTER 3 MOTION IN TWO DIMENSIONS 77

End-of-chapter resources

①

The photo shows fireworks erupting from Sydney Harbour Bridge. Note the shape of the paths taken by the incandescent embers. All the paths are a similar shape. Why do they take these particular trajectories, and how can we model their behaviour to allow us to predict their trajectories?

The embers can be modelled as particles in projectile motion. If we make the approximation that air resistance acting on the particles is small, then we expect them to all take parabolic paths. As you can see in the photo, the paths are approximately parabolic. If we could work out a scale for the photo, we would be able to make measurements on the photo to find the maximum height of any ember, and its launch angle θ. This gives us enough information to determine its initial velocity components using Equations 3.22 and 3.24. We could then calculate the position of an ember at any time after its launch using Equation 3.21. Note that we could work out an approximate scale using the known height of the bridge, which is 134 m.

Graham Monro/Photolibrary/ Jupiter Images

Figure 3.31
Fireworks erupt from the Sydney Harbour Bridge on New Year's Eve. Note the paths of the embers.

The problems found in this chapter may be assigned online in Enhanced Web Assign.

Worked solutions to every fifth problem are available in the Student Solutions Manual. Register online at **www.cengagebrain.com** for access.

②

Summary

Definitions

The **displacement vector** $\Delta\vec{\mathbf{r}}$ for a particle is the difference between its final position vector and its initial position vector:

$$\Delta\vec{\mathbf{r}} \equiv \vec{\mathbf{r}}_f - \vec{\mathbf{r}}_i \qquad (3.12)$$

The **average velocity** of a particle during the time interval Δt is defined as the displacement of the particle divided by the time interval:

$$\vec{\mathbf{v}}_{avg} \equiv \frac{\Delta\vec{\mathbf{r}}}{\Delta t} \qquad (3.13)$$

The **instantaneous velocity** of a particle is defined as the limit of the average velocity as Δt approaches zero:

$$\vec{\mathbf{v}} \equiv \lim_{\Delta t\to 0}\frac{\Delta\vec{\mathbf{r}}}{\Delta t} = \frac{d\vec{\mathbf{r}}}{dt} \qquad (3.14)$$

The **average acceleration** of a particle is defined as the change in its instantaneous velocity vector divided by the time interval Δt during which that change occurs:

$$\vec{\mathbf{a}}_{avg} \equiv \frac{\Delta\vec{\mathbf{v}}}{\Delta t} = \frac{\vec{\mathbf{v}}_f - \vec{\mathbf{v}}_i}{t_f - t_i} \qquad (3.15)$$

The **instantaneous acceleration** of a particle is defined as the limiting value of the average acceleration as Δt approaches zero:

$$\vec{\mathbf{a}} \equiv \lim_{\Delta t\to 0}\frac{\Delta\vec{\mathbf{v}}}{\Delta t} = \frac{d\vec{\mathbf{v}}}{dt} \qquad (3.16)$$

Projectile motion is one type of two-dimensional motion, exhibited by an object launched into the air near the Earth's surface and experiencing free fall. This common motion can be analysed by applying the particle with constant velocity model to the motion of the projectile in the x direction and the particle with constant acceleration model ($a_y = -g$) in the y direction.

A particle moving in a circular path with constant speed is exhibiting **uniform circular motion**.

Concepts and principles

If a particle moves with *constant* acceleration $\vec{\mathbf{a}}$ and has velocity $\vec{\mathbf{v}}_i$ and position $\vec{\mathbf{r}}_i$ at $t = 0$, its velocity and position vectors at some later time t are

$$\vec{\mathbf{v}}_f = \vec{\mathbf{v}}_i + \vec{\mathbf{a}}t \qquad (3.19)$$

$$\vec{\mathbf{r}}_f = \vec{\mathbf{r}}_i + \vec{\mathbf{v}}_i t + \frac{1}{2}\vec{\mathbf{a}}t^2 \qquad (3.20)$$

For two-dimensional motion in the xy plane under constant acceleration, each of these vector expressions is equivalent to two component expressions: one for the motion in the x direction and one for the motion in the y direction.

It is useful to think of projectile motion in terms of a combination of two analysis models: (1) the particle with constant velocity model in the x direction and (2) the particle with constant acceleration model in the vertical direction with a constant downwards acceleration of magnitude $g = 9.80\ \text{m/s}^2$.

If a particle moves along a curved path in such a way that both the magnitude and the direction of $\vec{\mathbf{v}}$ change in time, the particle has an acceleration vector that can be described by two component vectors: (1) a radial component vector $\vec{\mathbf{a}}_r$ that causes the change in direction of $\vec{\mathbf{v}}$ and (2) a tangential component vector $\vec{\mathbf{a}}_t$ that causes the change in magnitude of $\vec{\mathbf{v}}$. The magnitude of $\vec{\mathbf{a}}_r$ is v^2/r, and the magnitude of $\vec{\mathbf{a}}_t$ is $|dv/dt|$.

A particle in uniform circular motion has a radial acceleration $\vec{\mathbf{a}}_r$ because the direction of $\vec{\mathbf{v}}$ changes in time. This acceleration is called **centripetal acceleration**, and its direction is always towards the centre of the circle. It has no tangential acceleration.

78 PART 1 MECHANICS

The velocity $\vec{\mathbf{u}}_{PA}$ of a particle measured in a fixed frame of reference S_A can be related to the velocity $\vec{\mathbf{u}}_{PB}$ of the same particle measured in a moving frame of reference S_B by

$$\vec{\mathbf{u}}_{PA} = \vec{\mathbf{u}}_{PB} + \vec{\mathbf{v}}_{BA} \qquad (3.35)$$

where $\vec{\mathbf{v}}$ is the velocity of S_B relative to S_A.

Analysis model for problem solving

Particle in uniform circular motion If a particle moves in a circular path of radius r with a constant speed v, the magnitude of its centripetal acceleration is given by

$$a_c = \frac{v^2}{r} \qquad (3.26)$$

and the **period** of the particle's motion is given by

$$T = \frac{2\pi r}{v} \qquad (3.27)$$

and the **angular speed** of the particle is

$$\omega = \frac{2\pi}{T} \qquad (3.28)$$

Chapter review quiz

To help you revise Chapter 3: Motion in two dimensions, complete the automatically graded Chapter review quiz at http://login.cengagebrain.com.

③

Conceptual questions

1. A book is moved once around the perimeter of a table top with the dimensions 1 m by 2 m. The book ends up at its initial position. (a) What is its displacement? (b) What is the distance travelled?
2. Is it possible to add a vector quantity to a scalar quantity? Explain your answer.
3. Draw motion diagrams showing the velocity and acceleration of a projectile at several points along its path, assuming (a) the projectile is launched horizontally and (b) the projectile is launched at angle θ with the horizontal.
4. A spacecraft drifts through space at a constant velocity. Suddenly, a gas leak in the side of the spacecraft gives it a constant acceleration in a direction perpendicular to the initial velocity. The orientation of the spacecraft does not change, so the acceleration remains perpendicular to the original direction of the velocity. What is the shape of the path followed by the spacecraft in this situation?
5. Describe how a driver can steer a car travelling at constant speed so that (a) the acceleration is zero or (b) the magnitude of the acceleration remains constant.
6. An ice skater is executing a figure eight consisting of two identically shaped, tangent circular paths. Throughout the first loop she increases her speed uniformly, and during the second loop she moves at a constant speed. Draw a motion diagram showing her velocity and acceleration vectors at several points along the path of motion.
7. If you know the position vectors of a particle at two points along its path and also know the time interval during which it moved from one point to the other, can you determine the particle's instantaneous velocity? Its average velocity? Explain.

Problems

Section 3.1 Vectors, scalars and coordinate systems

1. The polar coordinates of a point are $r = 5.50$ m and $\theta = 240°$. What are the Cartesian coordinates of this point?
2. A fly lands on one wall of a room. The lower-left corner of the wall is selected as the origin of a two-dimensional Cartesian coordinate system. If the fly is located at the point having coordinates (2.00, 1.00) m, (a) how far is it from the origin? (b) What is its location in polar coordinates?
3. A vector has an x component of −25.0 units and a y component of 40.0 units. Find the magnitude and direction of this vector.
4. A person walks 25.0° north of east for 3.10 km. How far would she have to walk due north and due east to arrive at the same location?

Section 3.2 The position, velocity and acceleration vectors

5. A motorist drives south at 20.0 m/s for 3.00 min, then turns west and travels at 25.0 m/s for 2.00 min, and finally travels northwest at 30.0 m/s for 1.00 min. For this 6.00-min trip, find (a) the total vector displacement, (b) the average speed and (c) the average velocity. Let the positive x axis point east.
6. ±? When the Sun is directly overhead, a hawk dives towards the ground with a constant velocity of 5.0 ± 0.5 m/s at 60° ± 2° below the horizontal. Calculate the speed of its shadow on the level ground.
7. A golf ball is hit off a tee at the edge of a cliff. Its x and y coordinates as functions of time are given by $x = 18.0t$ and $y = 4.00t - 4.90t^2$, where x and y are in metres and t is in seconds. (a) Write a vector expression for the ball's position as a function of time, using the unit vectors $\hat{\mathbf{i}}$ and $\hat{\mathbf{j}}$. By taking derivatives, obtain expressions for (b) the velocity vector $\vec{\mathbf{v}}$ as a function of time and (c) the acceleration vector $\vec{\mathbf{a}}$ as a function of time. (d) Next, use unit-vector notation to write expressions for the position, the velocity, and the acceleration of the golf ball at $t = 3.00$ s.

Section 3.3 Two-dimensional motion with constant acceleration

8. The vector position of a particle varies in time according to the expression $\vec{\mathbf{r}} = 3.00\hat{\mathbf{i}} - 6.00t^2\hat{\mathbf{j}}$, where $\vec{\mathbf{r}}$ is in metres and t is in seconds. (a) Find an expression for the velocity of the particle as a function of time. (b) Determine the acceleration of the particle as a function of time. (c) Calculate the particle's position and velocity at $t = 1.00$ s.

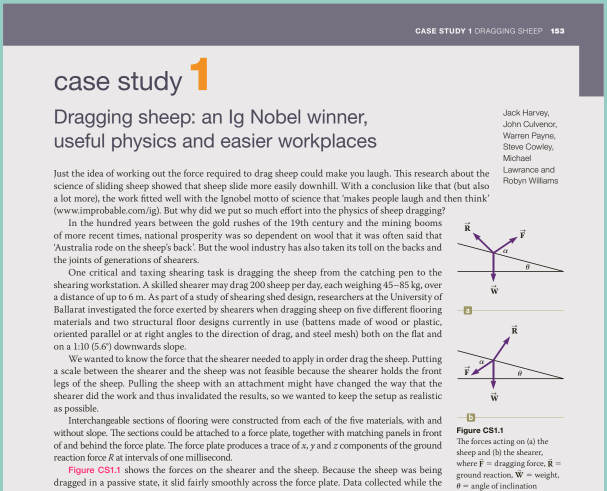
① Revisit the chapter opening **vignette** to see how the chapter has helped you to understand the concepts involved.

② **Definitions**, **Concepts and principles** and **Analysis for problem-solving sections** complete the **Summary** at the end of every chapter.

③ **Conceptual questions** and an extensive set of **Problems** are also included at the end of each chapter. About two thirds of the problems are keyed to specific sections of the chapter.

The **Additional problems** and **Challenge problems** will require you to synthesise key ideas from several sections.

CASE STUDIES



CASE STUDY 1 DRAGGING SHEEP 153

case study 1

Dragging sheep: an Ig Nobel winner, useful physics and easier workplaces

Jack Harvey,
John Culvenor,
Warren Payne,
Steve Cowley,
Michael
Lawrance and
Robyn Williams

Just the idea of working out the force required to drag sheep could make you laugh. This research about the science of sliding sheep showed that sheep slide more easily downhill. With a conclusion like that (but also a lot more), the work fitted well with the Ignobel motto of science that 'makes people laugh and then think' (www.improbable.com/ig). But why did we put so much effort into the physics of sheep dragging?

In the hundred years between the gold rushes of the 19th century and the mining booms of more recent times, national prosperity was so dependent on wool that it was often said that 'Australia rode on the sheep's back'. But the wool industry has also taken its toll on the backs and the joints of generations of shearers.

One critical and taxing shearing task is dragging the sheep from the catching pen to the shearing workstation. A skilled shearer may drag 200 sheep per day, each weighing 45–85 kg, over a distance of up to 6 m. As part of a study of shearing shed design, researchers at the University of Ballarat investigated the force exerted by shearers when dragging sheep on five different flooring materials and two structural floor designs currently in use (battens made of wood or plastic, oriented parallel or at right angles to the direction of drag, and steel mesh) both on the flat and on a 1:10 (5.6°) downwards slope.

We wanted to know the force that the shearer needed to apply in order drag the sheep. Putting a scale between the shearer and the sheep was not feasible because the shearer holds the front legs of the sheep. Pulling the sheep with an attachment might have changed the way that the shearer did the work and thus invalidated the results, so we wanted to keep the setup as realistic as possible.

Interchangeable sections of flooring were constructed from each of the five materials, with and without slope. The sections could be attached to a force plate, together with matching panels in front of and behind the force plate. The force plate produces a trace of x, y and z components of the ground reaction force R at intervals of one millisecond.

Figure CS1.1 shows the forces on the shearer and the sheep. Because the sheep was being dragged in a passive state, it slid fairly smoothly across the force plate. Data collected while the sheep was on the force plate were therefore less subject to impulse effects than data collected

Figure CS1.1
The forces acting on (a) the sheep and (b) the shearer, where $\vec{\mathbf{F}}$ = dragging force, $\vec{\mathbf{R}}$ = ground reaction, $\vec{\mathbf{W}}$ = weight, θ = angle of inclination of floor and α = angle of

International and regional **Case studies** have been written by practitioners from a wide range of disciplines and cover relevant applications and research in physics.

Guide to the online resources

FOR THE INSTRUCTOR

Cengage Learning is pleased to provide you with a selection of resources that will help you prepare your lectures and assessments. These teaching tools are accessible via cengage.com.au/instructors for Australia or cengage.co.nz/instructors for New Zealand.

Enhanced Web Assign is a powerful online instructional system with assignable questions taken directly from your textbook, powerful course analytics and a Gradebook. Instructors save time spent grading, and students receive instant feedback on problems. Key features include: all of the end-of-chapter Problems, Conceptual Questions, Quick Quizzes, Master It tutorials and multimedia Watch Its. Learn more at webassign.com.

Talk to your Learning Consultant about setting up Enhanced Web Assign for your course.

PowerLecture DVD

The **PowerLecture Instructor's Resource DVD** provides everything you need for Physics. Key content includes art and images from the text, PowerPoint lectures, ExamView test generator software with questions, instructor's manual, solutions to all questions and problems in the text, animated **Active Figure simulations**, and a **physics movie** library.

INSTRUCTOR'S MANUAL

The Instructor's Manual includes:

- learning objectives
- suggestions for lecture demonstrations
- example tutorial and lab class activities.

SOLUTIONS MANUAL

The Solutions Manual includes complete worked solutions to all the end-of-chapter conceptual questions and problems in the text.

WORD-BASED TEST BANK

This bank of questions has been developed with the text for the creation of quizzes, tests and exams for your students. Deliver tests from your LMS and your classroom.

POWERPOINT™ PRESENTATIONS

Use the chapter-by-chapter **PowerPoint presentations** to enhance your lectures and handouts in order to reinforce the key principles of your subject.

ARTWORK FROM THE TEXT

Add the digital files of figures, graphs and pictures into your course management system, use them in student handouts, or copy them into your lecture presentations.

FOR THE STUDENT

STUDENT COMPANION WEBSITE

Visit the Physics companion website. You'll find:

- Revision quizzes
- Active Figures
- Solutions to selected questions from the text
- Extra case studies
- Chapter summaries, and
- Useful weblinks.

ENHANCED WebAssign

Enhanced Web Assign has assignable online questions taken directly from your textbook including all of the end-of-chapter Problems, Conceptual Questions, Quick Quizzes, Master It tutorials, and multimedia Watch Its. Ask your Instructor for details on how to access activities in Enhanced Web Assign.

Electricity and magnetism

PART 5

The Australian Synchrotron in Melbourne uses electric and magnetic fields to accelerate and contain fast-moving charged particles. The accelerating particles emit electromagnetic radiation that is used for medical diagnostics and therapy, materials engineering and scientific research, among other applications.

Australian Synchrotron

We now study the branch of physics concerned with electric and magnetic phenomena. The laws of electricity and magnetism play a central role in the operation of all electrical and electronic devices, as well as electricity production and transmission, and natural phenomena such as lightning. More fundamentally, the interatomic and intermolecular forces responsible for the formation of solids and liquids are electric in origin.

Evidence in Chinese documents suggests magnetism was observed as early as 2000 BCE. The ancient Greeks knew about electric forces from rubbing amber on cloth to build up static charge, and about magnetic forces from observations that the naturally occurring stone *magnetite* (Fe_3O_4) is attracted to iron.

However, not until the early part of the 19th century did scientists establish through careful experiments that electricity and magnetism are related phenomena. In 1873, James Clerk Maxwell used these experiments as a basis for formulating the laws of electromagnetism as we know them today. Maxwell's contributions to the field of electromagnetism were especially significant because the laws he formulated are basic to *all* forms of electromagnetic phenomena.

In this section we study these laws of electricity and magnetism, and look at applications such as motors and generators, cyclotrons and synchrotrons, and simple AC (alternating current) and DC (direct current) electric circuits.

chapter 23

Electric fields

The physics lecturer shown is blowing bubbles past a Van de Graaff generator. Initially the stream of bubbles is drawn towards the dome of the generator, then their behaviour changes, and later bubbles fly away from the generator. Why are the first bubbles attracted to the generator and the later ones repelled by it?

On completing this chapter, students will understand:

- that charge can be positive or negative
- that charges exert forces on each other and that like charges repel and unlike charges attract
- that charging can occur by conduction or induction
- how the electrostatic force varies with distance for point charges
- how the electrostatic force can be described using a field
- that electric fields can be represented using field lines.

Students will be able to:

- describe the interaction of charged objects
- distinguish between charging by conduction and charging by induction
- use Coulomb's law to calculate the force on a charged object
- calculate the electric field due to discrete and continuous charge distributions
- draw electric field lines to represent electric fields
- analyse the motion of a charged particle in a uniform electric field.

In this chapter, we begin the study of electromagnetism. In Chapter 11 we met the first of the four fundamental forces – gravity. Gravity is the means by which particles with mass interact. The electromagnetic force is the means by which charged particles interact and is the second of the fundamental forces that we shall investigate. We begin by describing some basic properties of one manifestation of the electromagnetic force, the electrostatic force that exists between any two stationary charged particles. Just as the gravitational force due to an object can be described using the concept of a gravitational field, the electrostatic force due to an object can be described using an electric field. We shall look at the other fundamental forces – the strong and weak nuclear forces – later in this book.

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