



openstax™

College

Phys- ics

For AP[®] Courses

Advanced Placement[®] and AP[®] are trademarks registered and/or owned by the College Board, which was not involved in the production of, and does not endorse, this product.

College Physics for AP[®] Courses

SENIOR CONTRIBUTING AUTHORS

IRINA LYUBLINSKAYA, CUNY COLLEGE OF STATEN ISLAND

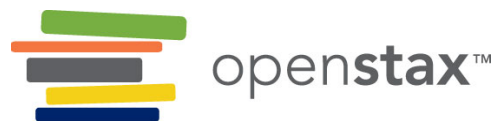
GREGG WOLFE, AVONWORTH HIGH SCHOOL

DOUGLAS INGRAM, TEXAS CHRISTIAN UNIVERSITY

LIZA PUJJI, MANUKAU INSTITUTE OF TECHNOLOGY

SUDHI OBEROI, RAMAN RESEARCH INSTITUTE

NATHAN CZUBA, SABIO ACADEMY



OpenStax

Rice University
6100 Main Street MS-375
Houston, Texas 77005

To learn more about OpenStax, visit <https://openstax.org>.
Individual print copies and bulk orders can be purchased through our website.

©2017 Rice University. Textbook content produced by OpenStax is licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0). Under this license, any user of this textbook or the textbook contents herein must provide proper attribution as follows:

- If you redistribute this textbook in a digital format (including but not limited to PDF and HTML), then you must retain on every page the following attribution:
"Download for free at <https://openstax.org/details/books/college-physics-ap-courses>."
- If you redistribute this textbook in a print format, then you must include on every physical page the following attribution:
"Download for free at <https://openstax.org/details/books/college-physics-ap-courses>."
- If you redistribute part of this textbook, then you must retain in every digital format page view (including but not limited to PDF and HTML) and on every physical printed page the following attribution:
"Download for free at <https://openstax.org/details/books/college-physics-ap-courses>."
- If you use this textbook as a bibliographic reference, please include <https://openstax.org/details/books/college-physics-ap-courses> in your citation.

For questions regarding this licensing, please contact support@openstax.org.

Trademarks

The OpenStax name, OpenStax logo, OpenStax book covers, OpenStax CNX name, OpenStax CNX logo, OpenStax Tutor name, Openstax Tutor logo, Connexions name, Connexions logo, Rice University name, and Rice University logo are not subject to the license and may not be reproduced without the prior and express written consent of Rice University.

PRINT BOOK ISBN-10	1-938168-93-3
PRINT BOOK ISBN-13	978-1-938168-93-2
PDF VERSION ISBN-10	1-947172-17-4
PDF VERSION ISBN-13	978-1-947172-17-3
ENHANCED TEXTBOOK PART 1 ISBN-10	1-938168-08-9
ENHANCED TEXTBOOK PART 1 ISBN-13	978-1-938168-08-6
ENHANCED TEXTBOOK PART 2 ISBN-10	1-938168-10-0
ENHANCED TEXTBOOK PART 2 ISBN-13	978-1-938168-10-9
Revision Number	CPFAC-2015-002(03/17)-BW
Original Publication Year	2015

OPENSTAX

OpenStax provides free, peer-reviewed, openly licensed textbooks for introductory college and Advanced Placement® courses and low-cost, personalized courseware that helps students learn. A nonprofit ed tech initiative based at Rice University, we're committed to helping students access the tools they need to complete their courses and meet their educational goals.

RICE UNIVERSITY

OpenStax, OpenStax CNX, and OpenStax Tutor are initiatives of Rice University. As a leading research university with a distinctive commitment to undergraduate education, Rice University aspires to path-breaking research, unsurpassed teaching, and contributions to the betterment of our world. It seeks to fulfill this mission by cultivating a diverse community of learning and discovery that produces leaders across the spectrum of human endeavor.



FOUNDATION SUPPORT

OpenStax is grateful for the tremendous support of our sponsors. Without their strong engagement, the goal of free access to high-quality textbooks would remain just a dream.



Laura and John Arnold Foundation (LJAF) actively seeks opportunities to invest in organizations and thought leaders that have a sincere interest in implementing fundamental changes that not only yield immediate gains, but also repair broken systems for future generations. LJAF currently focuses its strategic investments on education, criminal justice, research integrity, and public accountability.



The William and Flora Hewlett Foundation has been making grants since 1967 to help solve social and environmental problems at home and around the world. The Foundation concentrates its resources on activities in education, the environment, global development and population, performing arts, and philanthropy, and makes grants to support disadvantaged communities in the San Francisco Bay Area.



Calvin K. Kazanjian was the founder and president of Peter Paul (Almond Joy), Inc. He firmly believed that the more people understood about basic economics the happier and more prosperous they would be. Accordingly, he established the Calvin K. Kazanjian Economics Foundation Inc, in 1949 as a philanthropic, nonpolitical educational organization to support efforts that enhanced economic understanding.



Guided by the belief that every life has equal value, the Bill & Melinda Gates Foundation works to help all people lead healthy, productive lives. In developing countries, it focuses on improving people's health with vaccines and other life-saving tools and giving them the chance to lift themselves out of hunger and extreme poverty. In the United States, it seeks to significantly improve education so that all young people have the opportunity to reach their full potential. Based in Seattle, Washington, the foundation is led by CEO Jeff Raikes and Co-chair William H. Gates Sr., under the direction of Bill and Melinda Gates and Warren Buffett.



The Maxfield Foundation supports projects with potential for high impact in science, education, sustainability, and other areas of social importance.



Our mission at The Michelson 20MM Foundation is to grow access and success by eliminating unnecessary hurdles to affordability. We support the creation, sharing, and proliferation of more effective, more affordable educational content by leveraging disruptive technologies, open educational resources, and new models for collaboration between for-profit, nonprofit, and public entities.



The Bill and Stephanie Sick Fund supports innovative projects in the areas of Education, Art, Science and Engineering.

WOULDN'T THIS LOOK BETTER ON A BRAND NEW IPAD MINI?

Knowing where our textbooks are used can help us provide better services to students and receive more grant support for future projects.

If you're using an OpenStax textbook, either as required for your course or just as an extra resource, send your course syllabus to contests@openstax.org and you'll be entered to win an iPad Mini.

If you don't win, don't worry – we'll be holding a new contest each semester.



openstax™



RICE

Table of Contents

Preface	1
1 Introduction: The Nature of Science and Physics	7
Physics: An Introduction	8
Physical Quantities and Units	15
Accuracy, Precision, and Significant Figures	22
Approximation	27
2 Kinematics	33
Displacement	34
Vectors, Scalars, and Coordinate Systems	37
Time, Velocity, and Speed	39
Acceleration	43
Motion Equations for Constant Acceleration in One Dimension	55
Problem-Solving Basics for One Dimensional Kinematics	66
Falling Objects	67
Graphical Analysis of One Dimensional Motion	75
3 Two-Dimensional Kinematics	97
Kinematics in Two Dimensions: An Introduction	98
Vector Addition and Subtraction: Graphical Methods	101
Vector Addition and Subtraction: Analytical Methods	109
Projectile Motion	115
Addition of Velocities	123
4 Dynamics: Force and Newton's Laws of Motion	143
Development of Force Concept	146
Newton's First Law of Motion: Inertia	147
Newton's Second Law of Motion: Concept of a System	148
Newton's Third Law of Motion: Symmetry in Forces	154
Normal, Tension, and Other Examples of Force	159
Problem-Solving Strategies	167
Further Applications of Newton's Laws of Motion	169
Extended Topic: The Four Basic Forces—An Introduction	176
5 Further Applications of Newton's Laws: Friction, Drag, and Elasticity	193
Friction	194
Drag Forces	200
Elasticity: Stress and Strain	205
6 Gravitation and Uniform Circular Motion	223
Rotation Angle and Angular Velocity	224
Centripetal Acceleration	228
Centripetal Force	232
Fictitious Forces and Non-inertial Frames: The Coriolis Force	236
Newton's Universal Law of Gravitation	239
Satellites and Kepler's Laws: An Argument for Simplicity	247
7 Work, Energy, and Energy Resources	265
Work: The Scientific Definition	266
Kinetic Energy and the Work-Energy Theorem	270
Gravitational Potential Energy	275
Conservative Forces and Potential Energy	281
Nonconservative Forces	285
Conservation of Energy	290
Power	294
Work, Energy, and Power in Humans	298
World Energy Use	301
8 Linear Momentum and Collisions	319
Linear Momentum and Force	320
Impulse	323
Conservation of Momentum	327
Elastic Collisions in One Dimension	332
Inelastic Collisions in One Dimension	335
Collisions of Point Masses in Two Dimensions	339
Introduction to Rocket Propulsion	344
9 Statics and Torque	361
The First Condition for Equilibrium	362
The Second Condition for Equilibrium	363
Stability	368
Applications of Statics, Including Problem-Solving Strategies	372
Simple Machines	375
Forces and Torques in Muscles and Joints	379

10 Rotational Motion and Angular Momentum	395
Angular Acceleration	397
Kinematics of Rotational Motion	401
Dynamics of Rotational Motion: Rotational Inertia	406
Rotational Kinetic Energy: Work and Energy Revisited	411
Angular Momentum and Its Conservation	418
Collisions of Extended Bodies in Two Dimensions	424
Gyroscopic Effects: Vector Aspects of Angular Momentum	429
11 Fluid Statics	445
What Is a Fluid?	446
Density	447
Pressure	449
Variation of Pressure with Depth in a Fluid	453
Pascal's Principle	457
Gauge Pressure, Absolute Pressure, and Pressure Measurement	460
Archimedes' Principle	464
Cohesion and Adhesion in Liquids: Surface Tension and Capillary Action	470
Pressures in the Body	479
12 Fluid Dynamics and Its Biological and Medical Applications	495
Flow Rate and Its Relation to Velocity	496
Bernoulli's Equation	501
The Most General Applications of Bernoulli's Equation	505
Viscosity and Laminar Flow; Poiseuille's Law	509
The Onset of Turbulence	517
Motion of an Object in a Viscous Fluid	519
Molecular Transport Phenomena: Diffusion, Osmosis, and Related Processes	521
13 Temperature, Kinetic Theory, and the Gas Laws	535
Temperature	536
Thermal Expansion of Solids and Liquids	542
The Ideal Gas Law	549
Kinetic Theory: Atomic and Molecular Explanation of Pressure and Temperature	555
Phase Changes	562
Humidity, Evaporation, and Boiling	566
14 Heat and Heat Transfer Methods	583
Heat	584
Temperature Change and Heat Capacity	586
Phase Change and Latent Heat	592
Heat Transfer Methods	598
Conduction	599
Convection	605
Radiation	609
15 Thermodynamics	627
The First Law of Thermodynamics	628
The First Law of Thermodynamics and Some Simple Processes	634
Introduction to the Second Law of Thermodynamics: Heat Engines and Their Efficiency	642
Carnot's Perfect Heat Engine: The Second Law of Thermodynamics Restated	647
Applications of Thermodynamics: Heat Pumps and Refrigerators	652
Entropy and the Second Law of Thermodynamics: Disorder and the Unavailability of Energy	657
Statistical Interpretation of Entropy and the Second Law of Thermodynamics: The Underlying Explanation	664
16 Oscillatory Motion and Waves	681
Hooke's Law: Stress and Strain Revisited	683
Period and Frequency in Oscillations	687
Simple Harmonic Motion: A Special Periodic Motion	689
The Simple Pendulum	694
Energy and the Simple Harmonic Oscillator	696
Uniform Circular Motion and Simple Harmonic Motion	699
Damped Harmonic Motion	702
Forced Oscillations and Resonance	706
Waves	708
Superposition and Interference	711
Energy in Waves: Intensity	716
17 Physics of Hearing	731
Sound	732
Speed of Sound, Frequency, and Wavelength	734
Sound Intensity and Sound Level	739
Doppler Effect and Sonic Booms	744
Sound Interference and Resonance: Standing Waves in Air Columns	748
Hearing	757

Ultrasound	762
18 Electric Charge and Electric Field	781
Static Electricity and Charge: Conservation of Charge	784
Conductors and Insulators	789
Conductors and Electric Fields in Static Equilibrium	793
Coulomb's Law	797
Electric Field: Concept of a Field Revisited	799
Electric Field Lines: Multiple Charges	802
Electric Forces in Biology	806
Applications of Electrostatics	808
19 Electric Potential and Electric Field	831
Electric Potential Energy: Potential Difference	833
Electric Potential in a Uniform Electric Field	840
Electrical Potential Due to a Point Charge	845
Equipotential Lines	847
Capacitors and Dielectrics	851
Capacitors in Series and Parallel	859
Energy Stored in Capacitors	863
20 Electric Current, Resistance, and Ohm's Law	877
Current	878
Ohm's Law: Resistance and Simple Circuits	884
Resistance and Resistivity	887
Electric Power and Energy	893
Alternating Current versus Direct Current	896
Electric Hazards and the Human Body	900
Nerve Conduction—Electrocardiograms	905
21 Circuits, Bioelectricity, and DC Instruments	923
Resistors in Series and Parallel	924
Electromotive Force: Terminal Voltage	933
Kirchhoff's Rules	942
DC Voltmeters and Ammeters	948
Null Measurements	952
DC Circuits Containing Resistors and Capacitors	955
22 Magnetism	975
Magnets	976
Ferromagnets and Electromagnets	979
Magnetic Fields and Magnetic Field Lines	983
Magnetic Field Strength: Force on a Moving Charge in a Magnetic Field	984
Force on a Moving Charge in a Magnetic Field: Examples and Applications	987
The Hall Effect	991
Magnetic Force on a Current-Carrying Conductor	994
Torque on a Current Loop: Motors and Meters	996
Magnetic Fields Produced by Currents: Ampere's Law	999
Magnetic Force between Two Parallel Conductors	1004
More Applications of Magnetism	1006
23 Electromagnetic Induction, AC Circuits, and Electrical Technologies	1025
Induced Emf and Magnetic Flux	1026
Faraday's Law of Induction: Lenz's Law	1029
Motional Emf	1031
Eddy Currents and Magnetic Damping	1034
Electric Generators	1038
Back Emf	1041
Transformers	1042
Electrical Safety: Systems and Devices	1046
Inductance	1050
RL Circuits	1055
Reactance, Inductive and Capacitive	1056
RLC Series AC Circuits	1060
24 Electromagnetic Waves	1081
Maxwell's Equations: Electromagnetic Waves Predicted and Observed	1083
Production of Electromagnetic Waves	1085
The Electromagnetic Spectrum	1089
Energy in Electromagnetic Waves	1102
25 Geometric Optics	1115
The Ray Aspect of Light	1116
The Law of Reflection	1117
The Law of Refraction	1120
Total Internal Reflection	1125

Dispersion: The Rainbow and Prisms	1131
Image Formation by Lenses	1136
Image Formation by Mirrors	1149
26 Vision and Optical Instruments	1167
Physics of the Eye	1168
Vision Correction	1172
Color and Color Vision	1176
Microscopes	1179
Telescopes	1185
Aberrations	1188
27 Wave Optics	1199
The Wave Aspect of Light: Interference	1200
Huygens's Principle: Diffraction	1202
Young's Double Slit Experiment	1204
Multiple Slit Diffraction	1210
Single Slit Diffraction	1214
Limits of Resolution: The Rayleigh Criterion	1217
Thin Film Interference	1222
Polarization	1226
Extended Topic Microscopy Enhanced by the Wave Characteristics of Light	1235
28 Special Relativity	1251
Einstein's Postulates	1252
Simultaneity And Time Dilation	1254
Length Contraction	1261
Relativistic Addition of Velocities	1265
Relativistic Momentum	1270
Relativistic Energy	1272
29 Introduction to Quantum Physics	1289
Quantization of Energy	1291
The Photoelectric Effect	1294
Photon Energies and the Electromagnetic Spectrum	1297
Photon Momentum	1304
The Particle-Wave Duality	1308
The Wave Nature of Matter	1309
Probability: The Heisenberg Uncertainty Principle	1313
The Particle-Wave Duality Reviewed	1318
30 Atomic Physics	1331
Discovery of the Atom	1332
Discovery of the Parts of the Atom: Electrons and Nuclei	1334
Bohr's Theory of the Hydrogen Atom	1341
X Rays: Atomic Origins and Applications	1348
Applications of Atomic Excitations and De-Excitations	1353
The Wave Nature of Matter Causes Quantization	1361
Patterns in Spectra Reveal More Quantization	1364
Quantum Numbers and Rules	1366
The Pauli Exclusion Principle	1372
31 Radioactivity and Nuclear Physics	1391
Nuclear Radioactivity	1392
Radiation Detection and Detectors	1397
Substructure of the Nucleus	1399
Nuclear Decay and Conservation Laws	1404
Half-Life and Activity	1411
Binding Energy	1417
Tunneling	1421
32 Medical Applications of Nuclear Physics	1437
Medical Imaging and Diagnostics	1439
Biological Effects of Ionizing Radiation	1442
Therapeutic Uses of Ionizing Radiation	1449
Food Irradiation	1451
Fusion	1452
Fission	1458
Nuclear Weapons	1463
33 Particle Physics	1479
The Yukawa Particle and the Heisenberg Uncertainty Principle Revisited	1481
The Four Basic Forces	1483
Accelerators Create Matter from Energy	1485
Particles, Patterns, and Conservation Laws	1489
Quarks: Is That All There Is?	1494

GUTs: The Unification of Forces	1502
34 Frontiers of Physics	1517
Cosmology and Particle Physics	1517
General Relativity and Quantum Gravity	1525
Superstrings	1531
Dark Matter and Closure	1531
Complexity and Chaos	1535
High-Temperature Superconductors	1537
Some Questions We Know to Ask	1539
Appendix A: Atomic Masses	1549
Appendix B: Selected Radioactive Isotopes	1555
Appendix C: Useful Information	1559
Appendix D: Glossary of Key Symbols and Notation	1563
Index	1677

PREFACE

Welcome to *College Physics for AP[®] Courses*, an OpenStax resource. This textbook was written to increase student access to high-quality learning materials, maintaining highest standards of academic rigor at little to no cost.

About OpenStax

OpenStax is a nonprofit based at Rice University, and it's our mission to improve student access to education. Our first openly licensed college textbook was published in 2012, and our library has since scaled to over 25 books for college and AP[®] courses used by hundreds of thousands of students. Our adaptive learning technology, designed to improve learning outcomes through personalized educational paths, is being piloted in college courses throughout the country. Through our partnerships with philanthropic foundations and our alliance with other educational resource organizations, OpenStax is breaking down the most common barriers to learning and empowering students and instructors to succeed.

About OpenStax Resources

Customization

College Physics for AP[®] Courses is licensed under a Creative Commons Attribution 4.0 International (CC BY) license, which means that you can distribute, remix, and build upon the content, as long as you provide attribution to OpenStax and its content contributors.

Because our books are openly licensed, you are free to use the entire book or pick and choose the sections that are most relevant to the needs of your course. Feel free to remix the content by assigning your students certain chapters and sections in your syllabus, in the order that you prefer. You can even provide a direct link in your syllabus to the sections in the web view of your book.

Instructors also have the option of creating a customized version of their OpenStax book through the OpenStax Custom platform. The custom version can be made available to students in low-cost print or digital form through their campus bookstore. Visit your book page on openstax.org for a link to your book on OpenStax Custom.

Errata

All OpenStax textbooks undergo a rigorous review process. However, like any professional-grade textbook, errors sometimes occur. Since our books are web based, we can make updates periodically when deemed pedagogically necessary. If you have a correction to suggest, submit it through the link on your book page on openstax.org. Subject matter experts review all errata suggestions. OpenStax is committed to remaining transparent about all updates, so you will also find a list of past errata changes on your book page on openstax.org.

Format

You can access this textbook for free in web view or PDF through openstax.org, and in low-cost print and iBooks editions.

About *College Physics for AP[®] Courses*

College Physics for AP[®] Courses is designed to engage students in their exploration of physics and help them apply these concepts to the Advanced Placement[®] test. Because physics is integral to modern technology and other sciences, the book also includes content that goes beyond the scope of the AP[®] course to further student understanding. The AP[®] Connection in each chapter directs students to the material they should focus on for the AP[®] exam, and what content — although interesting — is not necessarily part of the AP[®] curriculum. This book is Learning List-approved for AP[®] Physics courses.

Coverage, Scope, and Alignment to the AP[®] Curriculum

The current AP[®] Physics curriculum framework outlines the two full-year physics courses AP[®] Physics 1: Algebra-Based and AP[®] Physics 2: Algebra-Based. These two courses replaced the one-year AP[®] Physics B course, which over the years had become a fast-paced survey of physics facts and formulas that did not provide in-depth conceptual understanding of major physics ideas and the connections between them.

AP[®] Physics 1 and 2 courses focus on the big ideas typically included in the first and second semesters of an algebra-based, introductory college-level physics course, providing students with the essential knowledge and skills required to support future advanced course work in physics. The AP[®] Physics 1 curriculum includes mechanics, mechanical waves, sound, and electrostatics. The AP[®] Physics 2 curriculum focuses on thermodynamics, fluid statics, dynamics, electromagnetism, geometric and physical optics, quantum physics, atomic physics, and nuclear physics. Seven unifying themes of physics called the Big Ideas each include three to seven enduring understandings (EU), which are themselves composed of essential knowledge (EK) that provides details and context for students as they explore physics.

AP[®] science practices emphasize inquiry-based learning and development of critical thinking and reasoning skills. Inquiry usually

uses a series of steps to gain new knowledge, beginning with an observation and following with a hypothesis to explain the observation; then experiments are conducted to test the hypothesis, gather results, and draw conclusions from data. The AP[®] framework has identified seven major science practices, which can be described by short phrases: using representations and models to communicate information and solve problems; using mathematics appropriately; engaging in questioning; planning and implementing data collection strategies; analyzing and evaluating data; justifying scientific explanations; and connecting concepts. The framework's Learning Objectives merge content (EU and EK) with one or more of the seven science practices that students should develop as they prepare for the AP[®] Physics exam.

College Physics for AP[®] Courses is based on the OpenStax *College Physics* text, adapted to focus on the AP curriculum's concepts and practices. Each chapter of OpenStax *College Physics for AP[®] Courses* begins with a *Connection for AP[®] Courses* introduction that explains how the content in the chapter sections align to the Big Ideas, enduring understandings, and essential knowledge in the AP[®] framework. This textbook contains a wealth of information, and the *Connection for AP[®] Courses* sections will help you distill the required AP[®] content from material that, although interesting, exceeds the scope of an introductory-level course.

Each section opens with the program's learning objectives as well as the AP[®] learning objectives and science practices addressed. We have also developed *Real World Connections* features and *Applying the Science Practices* features that highlight concepts, examples, and practices in the framework.

- 1 Introduction: The Nature of Science and Physics
- 2 Kinematics
- 3 Two-Dimensional Kinematics
- 4 Dynamics: Force and Newton's Laws of Motion
- 5 Further Applications of Newton's Laws: Friction, Drag, and Elasticity
- 6 Gravitation and Uniform Circular Motion
- 7 Work, Energy, and Energy Resources
- 8 Linear Momentum and Collisions
- 9 Statics and Torque
- 10 Rotational Motion and Angular Momentum
- 11 Fluid Statics
- 12 Fluid Dynamics and Its Biological and Medical Applications
- 13 Temperature, Kinetic Theory, and the Gas Laws
- 14 Heat and Heat Transfer Methods
- 15 Thermodynamics
- 16 Oscillatory Motion and Waves
- 17 Physics of Hearing
- 18 Electric Charge and Electric Field
- 19 Electric Potential and Electric Field
- 20 Electric Current, Resistance, and Ohm's Law
- 21 Circuits, Bioelectricity, and DC Instruments
- 22 Magnetism
- 23 Electromagnetic Induction, AC Circuits, and Electrical Technologies
- 24 Electromagnetic Waves
- 25 Geometric Optics
- 26 Vision and Optical Instruments
- 27 Wave Optics
- 28 Special Relativity
- 29 Introduction to Quantum Physics
- 30 Atomic Physics
- 31 Radioactivity and Nuclear Physics
- 32 Medical Applications of Nuclear Physics
- 33 Particle Physics
- 34 Frontiers of Physics
- Appendix A: Atomic Masses
- Appendix B: Selected Radioactive Isotopes
- Appendix C: Useful Information
- Appendix D: Glossary of Key Symbols and Notation

Pedagogical Foundation and Features

College Physics for AP[®] Courses is organized so that topics are introduced conceptually with a steady progression to precise definitions and analytical applications. The analytical, problem-solving aspect is tied back to the conceptual before moving on to another topic. Each introductory chapter, for example, opens with an engaging photograph relevant to the subject of the chapter and interesting applications that are easy for most students to visualize.

- **Connections for AP[®] Courses** introduce each chapter and explain how its content addresses the AP[®] curriculum.
- **Worked Examples** Examples start with problems based on real-life situations, then describe a strategy for solving the problem that emphasizes key concepts. The subsequent detailed mathematical solution also includes a follow-up

discussion.

- **Problem-solving Strategies** are presented independently and subsequently appear at crucial points in the text where students can benefit most from them.
- **Misconception Alerts** address common misconceptions that students may bring to class.
- **Take-Home Investigations** provide the opportunity for students to apply or explore what they have learned with a hands-on activity.
- **Real World Connections** highlight important concepts and examples in the AP[®] framework.
- **Applying the Science Practices** includes activities and challenging questions that engage students while they apply the AP[®] science practices.
- **Things Great and Small** explains macroscopic phenomena (such as air pressure) with submicroscopic phenomena (such as atoms bouncing off of walls).
- **PhET Explorations** link students to interactive PHeT physics simulations, developed by the University of Colorado, to help them further explore the physics concepts they have learned about in their book module.

Assessment

College Physics for AP[®] Courses offers a wealth of assessment options, including the following end-of-module problems:

- **Integrated Concept Problems** challenge students to apply both conceptual knowledge and skills to solve a problem.
- **Unreasonable Results** encourage students to solve a problem and then evaluate why the premise or answer to the problem are unrealistic.
- **Construct Your Own Problem** requires students to construct how to solve a particular problem, justify their starting assumptions, show their steps to find the solution to the problem, and finally discuss the meaning of the result.
- **Test Prep for AP[®] Courses** includes assessment items with the format and rigor found in the AP[®] exam to help prepare students for the exam.

AP Physics Collection

College Physics for AP[®] Courses is a part of the AP Physics Collection. The AP Physics Collection is a free, turnkey solution for your AP[®] Physics course, brought to you through a collaboration between OpenStax and Rice Online Learning. The integrated collection pairs the OpenStax College Physics for AP[®] Courses text with Concept Trailer videos, instructional videos, problem solution videos, and a correlation guide to help you align all of your content. The instructional videos and problem solution videos were developed by Rice Professor Jason Hafner and AP[®] Physics teachers Gigi Nevils-Noe and Matt Wilson through Rice Online Learning. You can access all of this free material through the College Physics for AP[®] Courses page on openstax.org.

Additional Resources

Student and Instructor Resources

We've compiled additional resources for both students and instructors, including Getting Started Guides, an instructor solution manual, and instructional videos. Instructor resources require a verified instructor account, which you can apply for when you log in or create your account on openstax.org. Take advantage of these resources to supplement your OpenStax book.

Partner Resources

OpenStax Partners are our allies in the mission to make high-quality learning materials affordable and accessible to students and instructors everywhere. Their tools integrate seamlessly with our OpenStax titles at a low cost. To access the partner resources for your text, visit your book page on openstax.org.

About the Authors

Senior Contributing Authors

Irina Lyublinskaya, CUNY College of Staten Island
Gregg Wolfe, Avonworth High School
Douglas Ingram, Trinity Christian University
Liza Pujji, Manukau Institute of Technology, New Zealand
Sudhi Oberoi, Visiting Research Student, QuIC Lab, Raman Research Institute, India
Nathan Czuba, Sabio Academy
Julie Kretchman, Science Writer, BS, University of Toronto
John Stoke, Science Writer, MS, University of Chicago
David Anderson, Science Writer, PhD, College of William and Mary
Erika Gasper, Science Writer, MA, University of California, Santa Cruz

Advanced Placement Teacher Reviewers

John Boehringer, Prosper High School
Victor Brazil, Petaluma High School
Michelle Burgess, Avon Lake High School
Bryan Callow, Lindenwold High School
Brian Hastings, Spring Grove Area School District

Alexander Lavy, Xavier High School
Jerome Mass, Glastonbury Public Schools

Faculty Reviewers

John Aiken, Georgia Institute of Technology
Robert Arts, University of Pikeville
Anand Batra, Howard University
Michael Ottinger, Missouri Western State University
James Smith, Caldwell University
Ulrich Zurcher, Cleveland State University

To the AP[®] Physics Student

The fundamental goal of physics is to discover and understand the “laws” that govern observed phenomena in the world around us. Why study physics? If you plan to become a physicist, the answer is obvious—introductory physics provides the foundation for your career; or if you want to become an engineer, physics provides the basis for the engineering principles used to solve applied and practical problems. For example, after the discovery of the photoelectric effect by physicists, engineers developed photocells that are used in solar panels to convert sunlight to electricity. What if you are an aspiring medical doctor? Although the applications of the laws of physics may not be obvious, their understanding is tremendously valuable. Physics is involved in medical diagnostics, such as x-rays, magnetic resonance imaging (MRI), and ultrasonic blood flow measurements. Medical therapy sometimes directly involves physics; cancer radiotherapy uses ionizing radiation. What if you are planning a nonscience career? Learning physics provides you with a well-rounded education and the ability to make important decisions, such as evaluating the pros and cons of energy production sources or voting on decisions about nuclear waste disposal.

This AP[®] Physics 1 course begins with **kinematics**, the study of motion without considering its causes. Motion is everywhere: from the vibration of atoms to the planetary revolutions around the Sun. Understanding motion is key to understanding other concepts in physics. You will then study **dynamics**, which considers the forces that affect the motion of moving objects and systems. Newton’s laws of motion are the foundation of dynamics. These laws provide an example of the breadth and simplicity of the principles under which nature functions. One of the most remarkable simplifications in physics is that only four distinct forces account for all known phenomena. Your journey will continue as you learn about energy. Energy plays an essential role both in everyday events and in scientific phenomena. You can likely name many forms of energy, from that provided by our foods, to the energy we use to run our cars, to the sunlight that warms us on the beach. The next step is learning about oscillatory motion and waves. All oscillations involve force and energy: you push a child in a swing to get the motion started and you put energy into a guitar string when you pluck it. Some oscillations create waves. For example, a guitar creates sound waves. You will conclude this first physics course with the study of static electricity and electric currents. Many of the characteristics of static electricity can be explored by rubbing things together. Rubbing creates the spark you get from walking across a wool carpet, for example. Similarly, lightning results from air movements under certain weather conditions.

In the AP[®] Physics 2 course, you will continue your journey by studying **fluid dynamics**, which explains why rising smoke curls and twists and how the body regulates blood flow. The next stop is **thermodynamics**, the study of heat transfer—energy in transit—that can be used to do work. Basic physical laws govern how heat transfers and its efficiency. Then you will learn more about electric phenomena as you delve into **electromagnetism**. An electric current produces a magnetic field; similarly, a magnetic field produces a current. This phenomenon, known as **magnetic induction**, is essential to our technological society. The generators in cars and nuclear plants use magnetism to generate a current. Other devices that use magnetism to induce currents include pickup coils in electric guitars, transformers of every size, certain microphones, airport security gates, and damping mechanisms on sensitive chemical balances. From electromagnetism you will continue your journey to **optics**, the study of light. You already know that visible light is the type of electromagnetic waves to which our eyes respond. Through vision, light can evoke deep emotions, such as when we view a magnificent sunset or glimpse a rainbow breaking through the clouds. Optics is concerned with the generation and propagation of light. The **quantum mechanics**, **atomic physics**, and **nuclear physics** are at the end of your journey. These areas of physics have been developed at the end of the 19th and early 20th centuries and deal with submicroscopic objects. Because these objects are smaller than we can observe directly with our senses and generally must be observed with the aid of instruments, parts of these physics areas may seem foreign and bizarre to you at first. However, we have experimentally confirmed most of the ideas in these areas of physics.

AP[®] Physics is a challenging course. After all, you are taking physics at the introductory college level. You will discover that some concepts are more difficult to understand than others; most students, for example, struggle to understand rotational motion and angular momentum or particle-wave duality. The AP[®] curriculum promotes depth of understanding over breadth of content, and to make your exploration of topics more manageable, concepts are organized around seven major themes called the **Big Ideas** that apply to all levels of physical systems and interactions between them (see web diagram below). Each Big Idea identifies **enduring understandings** (EU), **essential knowledge** (EK), and **illustrative examples** that support key concepts and content. Simple descriptions define the focus of each Big Idea.

- Big Idea 1: Objects and systems have properties.
- Big Idea 2: Fields explain interactions.
- Big Idea 3: The interactions are described by forces.
- Big Idea 4: Interactions result in changes.
- Big Idea 5: Changes are constrained by conservation laws.
- Big Idea 6: Waves can transfer energy and momentum.
- Big Idea 7: The mathematics of probability can describe the behavior of complex and quantum mechanical systems.

Doing college work is not easy, but completion of AP[®] classes is a reliable predictor of college success and prepares you for subsequent courses. The more you engage in the subject, the easier your journey through the curriculum will be. Bring your enthusiasm to class every day along with your notebook, pencil, and calculator. Prepare for class the day before, and review concepts daily. Form a peer study group and ask your teacher for extra help if necessary. The AP[®] lab program focuses on more open-ended, student-directed, and inquiry-based lab investigations designed to make you think, ask questions, and analyze data like scientists. You will develop critical thinking and reasoning skills and apply different means of communicating information. By the time you sit for the AP[®] exam in May, you will be fluent in the language of physics; because you have been doing real science, you will be ready to show what you have learned. Along the way, you will find the study of the world around us to be one of the most relevant and enjoyable experiences of your high school career.

Irina Lyublinskaya, PhD
Professor of Science Education

To the AP[®] Physics Teacher

The AP[®] curriculum was designed to allow instructors flexibility in their approach to teaching the physics courses. *College Physics for AP[®] Courses* helps you orient students as they delve deeper into the world of physics. Each chapter includes a Connection for AP[®] Courses introduction that describes the AP[®] Physics Big Ideas, enduring understandings, and essential knowledge addressed in that chapter.

Each section starts with specific AP[®] learning objectives and includes essential concepts, illustrative examples, and science practices, along with suggestions for applying the learning objectives through take-home experiments, virtual lab investigations, and activities and questions for preparation and review. At the end of each section, students will find the Test Prep for AP[®] courses with multiple-choice and open-response questions addressing AP[®] learning objectives to help them prepare for the AP[®] exam.

College Physics for AP[®] Courses has been written to engage students in their exploration of physics and help them relate what they learn in the classroom to their lives outside of it. Physics underlies much of what is happening today in other sciences and in technology. Thus, the book content includes interesting facts and ideas that go beyond the scope of the AP[®] course. The AP[®] Connection in each chapter directs students to the material they should focus on for the AP[®] exam, and what content—although interesting—is not part of the AP[®] curriculum. Physics is a beautiful and fascinating science. It is in your hands to engage and inspire your students to dive into an amazing world of physics, so they can enjoy it beyond just preparation for the AP[®] exam.

Irina Lyublinskaya, PhD
Professor of Science Education



The concept map showing major links between Big Ideas and Enduring Understandings is provided below for visual reference.