



Course

General Physics

Volume I

Number

PHYSICS 201

Robert Endorf

University Of Cincinnati

PHYSICS



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Numerical Constants

Name	Symbol	Value
Speed of light in vacuum	С	2.99792458 · 10 ⁸ m s ⁻¹
Elementary charge	e	1.602176487(40) · 10 ⁻¹⁹ C
Universal gravitational constant	G	$6.67428(67) \cdot 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-1}$
Planck's constant	h	$6.62606896(33) \cdot 10^{-34} \text{ J s}$
Boltzmann's constant	$k_{ m B}$	$1.3806504(24) \cdot 10^{-23} \text{ J K}^{-1}$
Avogadro's number	$N_{\rm A}$	$6.02214179(30) \cdot 10^{23} \text{ mol}^{-1}$
Universal gas constant	R	8.314472(15) J mol ⁻¹ K ⁻¹
Mass of an electron	$m_{\rm e}$	$9.10938215(45) \cdot 10^{-31} \text{ kg}$
Mass of a proton	$m_{ m p}$	1.672621637(83) · 10 ⁻²⁷ kg
Mass of a neutron	$m_{ m n}$	1.674927211(84) · 10 ⁻²⁷ kg
Magnetic permeability of free space	μ_0	$4\pi \cdot 10^{-7} \text{ N A}^{-2}$
Electric permittivity of free space	$\epsilon_0 = 1/(\mu_0 c^2)$	$8.854187817 \cdot 10^{-12} \text{ N A}^{-2}$
Stefan-Boltzmann constant	σ	5.760400(40) · 10 ⁻⁸ W m ⁻² K ⁻⁴

Source: National Institute of Standards and Technology, http://physics.nist.gov/constants. The numbers in parentheses show the uncertainty in the final digits of the quoted number. For example, 6.67428(67) means 6.67428 ± 0.00067 . Values shown without uncertainties are exact.

Name	Symbol	Value
Standard acceleration due to gravity	g	9.81 m s ⁻²
Standard atmospheric pressure at 20 °C	atm	1.01325 · 10 ⁵ Pa
Volume of ideal gas at 0 °C and 1 atm		22.413996(39) liter/mol
Mechanical equivalent of heat		4.186 J/cal
Atomic mass unit	u	1.660538782(83) kg
Electron-volt	eV	1.602176487(40) · 10 ⁻¹⁹ J
Atomic mass unit energy equivalent	uc^2	931.494028(23) MeV
Electron mass energy equivalent	$m_e c^2$	0.510998910(13) MeV
Proton mass energy equivalent	$m_{\rm p}c^2$	938.272013(23) MeV
Neutron mass energy equivalent	$m_{\rm n}c^2$	939.565346(23) MeV
Planck's constant divided by 2π	ħ	1.054571628(53) · 10 ⁻³⁴ J s
Planck's constant divided by 2π times c	ħс	197.3269631(49) MeV fm
Bohr radius	a_0	0.52917720859(36) · 10 ⁻¹⁰ m

Source: National Institute of Standards and Technology, http://physics.nist.gov/constants. The numbers in parentheses show the uncertainty in the final digits of the quoted number. For example, 6.67428(67) means 6.67428 ± 0.00067 . Values shown without uncertainties are exact.

Unit Conversion Factors

Length

 $1 \text{ m} = 100 \text{ cm} = 1000 \text{ mm} = 10^6 \text{ } \mu\text{m} = 10^9 \text{ nm}$

1 km = 1000 m = 0.6214 mi

1 m = 3.281 ft = 39.37 in

1 cm = 0.3937 in

1 in = 2.54 cm (exactly)

1 ft = 30.48 cm (exactly)

1 yd = 91.44 cm (exactly)

1 mi = 5280 ft = 1.609344 km (exactly)

 $1 \text{ Angstrom} = 10^{-10} \text{ m} = 10^{-8} \text{ cm} = 0.1 \text{ nm}$

1 nautical mile = 6080 ft = 1.152 mi

1 light-year = $9.461 \cdot 10^{15}$ m

Area

 $1 \text{ m}^2 = 10^4 \text{ cm}^2 = 10.76 \text{ ft}^2$

 $1 \text{ cm}^2 = 0.155 \text{ in}^2$

 $1 \text{ in}^2 = 6.452 \text{ cm}^2$

 $1 \text{ ft}^2 = 144 \text{ in}^2 = 0.0929 \text{ m}^2$

1 hectare = 2.471 acre = 10000 m^2

 $1 \text{ acre} = 0.4047 \text{ hectare} = 43560 \text{ ft}^2$

 $1 \text{ mi}^2 = 640 \text{ acre}$

 $1 \text{ yd}^2 = 0.8361 \text{ m}^2$

Volume

1 liter = $1000 \text{ cm}^3 = 10^{-3} \text{m}^3 = 0.03531 \text{ ft}^3 = 61.02 \text{ in}^3 =$

33.81 fluid ounce

 $1 \text{ ft}^3 = 0.02832 \text{ m}^3 = 28.32 \text{ liter} = 7.477 \text{ gallon}$

1 gallon = 3.788 liters

1 quart = 0.9463 liter

Time

 $1 \min = 60 \text{ s}$

1 h = 3,600 s

1 day = 86,400 s

1 week = 604,800 s

1 year = $3.156 \cdot 10^7$ s

Angle

 $1 \text{ rad} = 57.30^{\circ} = 180^{\circ}/\pi$

 $1^{\circ} = 0.01745 \text{ rad} = (\pi/180) \text{ rad}$

 $1 \text{ rev} = 360^{\circ} = 2\pi \text{ rad}$

 $1 \text{ rev/min (rpm)} = 0.1047 \text{ rad/s} = 6^{\circ}/\text{s}$

Speed

1 mile per hour (mph) = 0.4470 m/s = 1.466 ft/s = 1.609 km/h

1 m/s = 2.237 mph = 3.281 ft/s

1 km/h = 0.2778 m/s = 0.6214 mph

1 ft/s = 0.3048 m/s

1 knot = 1.151 mph = 0.5144 m/s

Acceleration

 $1 \text{ m/s}^2 = 100 \text{ cm/s}^2 = 3.281 \text{ ft/s}^2$

 $1 \text{ cm/s}^2 = 0.01 \text{ m/s}^2 = 0.03281 \text{ ft/s}^2$

 $1 \text{ ft/s}^2 = 0.3048 \text{ m/s}^2 = 30.48 \text{ cm/s}^2$

Mass

1 kg = 1000 g = 0.0685 slug

1 slug =14.95 kg

1 kg has a weight of 2.205 lb when $g = 9.807 \text{ m/s}^2$

1 lb has a mass of 0.4546 kg when $g = 9.807 \text{ m/s}^2$

Force

1 N = 0.2248 lb

1 lb = 4.448 N

1 stone = 14 lb = 62.27 N

Pressure

1 Pa = 1 N/m² = $1.450 \cdot 10^{-4}$ lb/in² = 0.209 lb/ft²

1 atm = $1.013 \cdot 10^5$ Pa = 101.3 kPa = 14.7 lb/in² = 2117 lb/ft² =

760 mm Hg = 29.92 in Hg

 $1 \text{ lb/in}^2 = 6895 \text{ Pa}$

 $1 \text{ lb/ft}^2 = 47.88 \text{ Pa}$

1 mm Hg = 1 torr = 133.3 Pa

 $1 \text{ bar} = 10^5 \text{ Pa} = 100 \text{ kPa}$

Energy

1 J = 0.239 cal

1 cal = 4.186 J

1 Btu = 1055 J = 252 cal

 $1 \text{ kW} \cdot \text{h} = 3.600 \cdot 10^6 \text{ J}$

1 ft·lb =1.356 J

 $1 \text{ eV} = 1.602 \cdot 10^{-19} \text{ J}$

Power

1 W = 1 J s

 $1 \text{ hp} = 746 \text{ W} = 0.746 \text{ kW} = 550 \text{ ft} \cdot \text{lb/s}$

1 Btu/h = 0.293 W

 $1 \text{ GW} = 1000 \text{ MW} = 1.0 \cdot 10^9 \text{ W}$

1 kW = 1.34 hp

Temperature

Fahrenheit to Celsius: $T_C = \frac{5}{9}(T_F - 32 \text{ °F})$

Celsius to Fahrenheit: $T_F = \frac{9}{5}T_C + 32$ °C

Celsius to Kelvin: $T_{\rm K} = T_{\rm C} + 273.15$ °C

Kelvin to Celsius: $T_C = T_K - 273.15 \text{ K}$

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WELCOME TO GENERAL PHYSICS I AT THE UNIVERSITY OF CINCINNATI

The Physics Department would like to welcome you as a student in our General Physics I course. This textbook, UniversityPhysics by Wolfgang Bauer and Gary Westfall, has been custom published for students enrolled in General Physics I (15-PHYS-201) at the University of Cincinnati. It contains only those chapters, which will be covered during the first quarter of General Physics at the University of Cincinnati. This course is a calculus-based introduction covering the most important topics in physics. General Physics I will cover Classical Mechanics, the scientific study of the motion of objects. Physics is the most fundamental science and provides the foundation for engineering and the other sciences. This course will emphasize the basic physics principles and concepts needed to understand the physical universe. The course will focus on developing an understanding of physical phenomena by building models and theories based on fundamental principles. Students will be expected be able to solve physics problems by using the fundamental principles and theories of physics and not just "plugging" numbers into equations or reproducing memorized facts. You may find General Physics to be a challenging course, but we hope that you will also find it to be an exciting and rewarding course that will help you in your future studies and endeavors.

Overall information about the General Physics I course is contained here for your reference. Specific information about your General Physics course will be presented on the Blackboard Course for your particular General Physics class.

GENERAL PHYSICS I COURSE INFORMATION

COURSE GOALS: The topic for General Physics I is mechanics, the scientific study of motion. The goals for General Physics I are to achieve an understanding of the basic concepts of mechanics and be able to apply these concepts to a variety of physical situations. Students are expected to acquire skills in scientific methods, critical reasoning, and problem solving. Students are also expected to learn to organize their thoughts clearly and to express them clearly in both written and oral communication.

PRE-REQUISITE OR CO-REQUISITE: Calculus I

BLACKBOARD: Students should frequently check the General Physics Blackboard course site for course information, such as assigned homework problems, practice exams, exam solutions and any updated course information. An updated course syllabus will be maintained on Blackboard.

LABORATORY: You should be co-registered in the laboratory course, 15-PHYS-211 for General Physics I, unless your program does not require the laboratory. The laboratory manual will be available through Blackboard. There will be printed laboratory manuals available only at the UC bookstore. Procedures, grading policy, etc. for the lab course will be discussed during the first laboratory class meeting.

ATTENDANCE: Students are expected to attend all classes.

ABSENCES: Except for emergencies, students are expected to inform their instructor if they cannot attend an exam. Makeup exams may be arranged at the discretion of the lecture instructor, if a student has a valid excuse for the absence.

CONDUCT: The University Rules, including the Student Code of Conduct, and other documented policies of the department, college, and university related to academic integrity will be enforced. Any violation of these regulations, including acts of plagiarism or cheating, will be dealt with on an individual basis according to the severity of the misconduct.

PHYSICS LEARNING CENTER (Room 303, Geology/Physics Building):

The Physics Learning Center, staffed by faculty and graduate students, is available to provide students help with physics problems. The schedule for the Learning Center will be posted.

SPECIAL NEEDS: If you have any special needs related to your participation in this course, including identified visual impairment, hearing impairment, physical impairment, communication disorder, and/or specific learning disability that may influence your performance in this course, you should meet with the instructor to arrange for reasonable provisions to ensure an equitable opportunity to meet all the requirements of this course. At the discretion of the instructor, some accommodations may require prior approval by Disability Services.

WITHDRAWAL: Students will be allowed to withdraw and receive a grade of "W," up to official class withdrawal date, regardless of their score in the course. However, they must obtain the signature of the lecture instructor.

REQUIREMENTS FULFILLED: This course satisfies the General Education Breadth of Knowledge Competencies in the areas of Natural Science and Quantitative Reasoning. It also satisfies the College of Arts and Sciences course requirement in Natural Sciences.

PROCEDURE FOR SOLVING GENERAL PHYSICS PROBLEMS

Listed below is a systematic procedure and format, devised by Dr. Endorf, to help students solve general physics problems. The solutions should be written in the format shown in the Problem Worksheet.

- 1. Read the problem carefully. Make sure you understand what is given in the problem and what you are requested to find. Write a description of the problem in your own words on the Problem Worksheet.
- 2. If applicable, draw a diagram showing all relevant features given in the problem. Label each part of the diagram, using symbols for each quantity. For vectors show their vector components, where appropriate. For kinematics problems show a motion diagram. For problems involving forces, draw all forces acting on each body under consideration. For systems changing with time, show the initial, intermediate and final configurations of the system. Indicate relevant parameters that change with time.
- 3. List all the known quantities and their values on the Problem Worksheet. Convert the values of the known quantities to a consistent set of units, usually SI units.
- 4. List the quantities to be calculated on the Problem Worksheet.
- 5. List all relevant unknown parameters on the Problem Worksheet. These may need to be eliminated from the solution or calculated before calculating the quantities requested in the problem.
- 6. List all relevant general principles, laws, equations and facts that apply to this problem.
- 7. Devise a method to solve the problem. Consider how you may use the general principles and laws that you listed above, such as Newton's Laws, the conservation of energy, and the conservation of linear and angular momentum. For systems changing with time, show the initial, intermediate and final configurations of the system. Indicate relevant parameters that change with time, such as types of energy or the momenta of particles. The solution may require several steps. Write an outline on the Problem Worksheet, in words, of each step that you will use in your solution.
- 8. Write the problem solution in a clear manner, using your method, on the Problem Worksheet. First solve the problem with algebraic symbols. Then, if a numerical answer is requested, input the numerical values (with units) of the known quantities and calculate the values of the requested unknown quantities. Check that the calculated quantities have the proper units. Check that the answers you have calculated make sense. For example, are the answers much too large or much too small? Do they have the correct sign? For certain very simple conditions do you get the correct answers?

GENERAL PHYSICS PROBLEM WORKSHEET

PROBLEM #	DATE:	Sec.#
NAME(S)_ PROBLEM DESCRIPTION	•	
TROBLEM DESCRIPTION	•	
DIAGRAM: (if applicable)		
KNOWN QUANTITIES:		
QUANTITIES TO BE CALC	ULATED:	
RELEVANT UNKNOWN PA	ARAMETERS:	
RELEVANT GENERAL PRI	INCIPLES, LAWS, E	QUATIONS AND FACTS:
METHOD OF SOLUTION:	(general outline of s	colution method in words)
PROBLEM SOLUTION: (1. First, solve algebraically sense.)	y; 2. check units; 3.	check that the answer(s) make(s)

SUGGESTIONS FOR DOING WELL IN GENERAL PHYSICS

Listed below are a set of suggestions or strategies, complied by Dr. Robert Endorf, to help students learn physics and perform well in the General Physics.

STUDY HINTS:

- 1. Form a study group to discuss problems and help study for exams and quizzes. Each member of the study group should contribute and understand the material.
- 2. Read the entire chapter quickly to obtain the main ideas and concepts.
- 3. Re read each section of the chapter slowly trying to understand each idea the author presents.
- 4. Before going to lecture class, read the topics from the text that will be covered in class. Attend all lecture classes. For lecture sections using "clickers," participate in the class discussion and diligently answer all of the "clicker" questions.
- 5. Ask questions in class or after class about confusing subject matter.
- 6. Attend all recitation classes and participate enthusiastically in your cooperative learning group.
- 7. Work through all example problems in the text and all examples given in class.
- 8. Read and understand the summary at the end of the each chapter.
- 9. Write your own review notes. Include the facts and equations you need to solve problems, but emphasize the basic principles and laws needed to solve problems. Update your notes as needed while solving the problems. Try to construct an overall model that relates the basic concepts and principles to the real world.
- 10. Work on all the assigned homework problems. Use the problem solving strategies and format listed in the *Procedure for Solving Physics Problems* for doing your homework problems. Focus on using general physical principles to classify and solve the problems. Complete all lecture, online web-based homework and recitation homework.
- 11. Discuss the problems in your study group. Write your own solutions for each problem.
- 12. Do not get behind on the scheduled material and problems. Try to spend some time, at least every other day, studying physics and working problems.
- 13. If help is needed, ask for help at the Physics Learning Center, in recitation, the professor's office hours or the recitation instructor's office hours.
- 14. For extra help, use the textbook, web-based study resources, and any student workbooks.

HINTS FOR TAKING EXAMS AND QUIZZES:

A. Before the Exam:

- 1. Review the summaries in the text, your class notes and your review notes.
- 2. Study all examples done in class.
- 3. Study all sample problems in the text.

 (Try solving the problems with the solutions covered.)
- 4. Study all assigned problems.
- 5. Try taking a sample exam. Pick several sample problems or assigned problems and try to solve each problem, with no aids, in a time of 20 minutes or less.
- 6. Take the Practice Exam and use it as a guide for additional topics that you may need to study.

B. During the Exam:

- 1. First, read each exam problem. Concentrate on solving the problems using general principles and problem solving strategies.
- 2. Begin with the problem you find the easiest.
- 3. Write neatly. Draw a diagram. Show all your work and explain your answers.
- 4. Algebraically list all equations as they are used in the problem. **Solve problems** with symbols, then insert the numbers.
- 5. If unable to solve one part of a problem, go to the next part.
- 6. Check the units of your answer. Check that your answer makes sense. Make sure all items requested are answered.
- 7. Allocate enough time for each problem. If stuck on one problem go to the next problem and return to where you got stuck later.
- 8. If time is available, recheck each problem before submitting the exam.

C. After the Exam:

- 1. Check the posted exam solutions.
- 2. Make sure that you understand the solution of each problem.
- 3. If any errors were made in grading your exam submit it to your instructor for a regrade.
- 4. Save all exams, guizzes and homework for future reference.

If you have any general questions or comments about the General Physics courses, please contact the General Physics Course Coordinator, Dr. Robert Endorf, Professor of Physics, at the email address: Robert.Endorf@UC.edu.



A Note from the Authors

Physics is a thriving science, alive with intellectual challenge and presenting innumerable research problems on topics ranging from the largest galaxies to the smallest subatomic particles. Physicists have managed to bring understanding, order, consistency, and predictability to our universe and will continue that endeavor into the exciting future.

However, when we open most current introductory physics textbooks, we find that a different story is being told. Physics is painted as a completed science in which the major advances happened at the time of Newton, or perhaps early in the 20th century. Only toward the end of the standard textbooks is "modern" physics covered, and even that coverage often includes only discoveries made through the 1960s.

Our main motivation to write this book is to change this perception by appropriately weaving exciting, contemporary physics throughout the text. Physics is an exciting, dynamic discipline—continuously on the verge of new discoveries and life-changing applications. In order to help students see this, we need to tell the full, exciting story of our science by appropriately integrating contemporary physics into the first-year calculus-based course. Even the very first semester offers many opportunities to do this by weaving recent results from non-linear dynamics, chaos, complexity, and high-energy physics research into the introductory curriculum. Because we are actively carrying out research in these fields, we know that many of the cutting-edge results are accessible in their essence to the first-year student.

Authors in many other fields, such as biology and chemistry, already weave contemporary research into their textbooks, recognizing the substantial changes that are affecting the foundations of their disciplines. This integration of contemporary research gives students the impression that biology and chemistry are the "hottest" research enterprises around. The foundations of physics, on the other hand, are on much firmer ground, but the new advances are just as intriguing and exciting, if not more so. We need to find a way to share the advances in physics with our students.

We believe that talking about the broad topic of energy provides a great opening gambit to capture students' interest. Concepts of energy sources (fossil, renewable, nuclear, and so forth),

energy efficiency, alternative energy sources, and environmental effects of energy supply choices (global warming) are very much accessible on the introductory physics level. We find that discussions of energy spark our students' interest like no other current topic, and we have addressed different aspects of energy throughout our book.

In addition to being exposed to the exciting world of physics, students benefit greatly from gaining the ability to **problem solve and think logically about a situation**. Physics is based on a core set of ideas that is fundamental to all of science. We acknowledge this and provide a useful problem-solving method (outlined in Chapter 1) which is used throughout the entire book. This problem-solving method involves a multi-step format that both of us have developed with students in our classes.

With all of this in mind along with the desire to write a captivating textbook, we have created what we hope will be a tool to engage students' imaginations and to better prepare them for future courses in their chosen fields (admittedly, hoping that we would convert at least a few students to physics majors along the way). Having feedback from more than 300 people, including a board of advisors, several contributors, manuscript reviewers, and focus group participants, assisted greatly in this enormous undertaking, as did field testing of our ideas with approximately 4000 students in our introductory physics classes at Michigan State University. We thank you all!



Preface

University Physics is intended for use in the calculus-based introductory physics sequence at universities and colleges. It can be used in either a two-semester introductory sequence or a three-semester sequence. The course is intended for students majoring in the biological sciences, the physical sciences, mathematics, and engineering.

Problem-Solving Skills: Learning to Think Like a Scientist

Perhaps one of the greatest skills students can take from their physics course is the ability to problem solve and think critically about a situation. Physics is based on a core set of fundamental ideas that can be applied to various situations and problems. *University Physics* by Bauer and Westfall acknowledges this and provides a problem-solving method class tested by the authors, and used throughout the entire text. The text's problem-solving method involves a multi-step format.

"The Problem-Solving Guidelines help students improve their problem-solving skills, by teaching them how to break a word problem down to its key components. The key steps in writing correct equations are nicely described and are very helpful for students."

-Nina Abramzon, California Polytechnic University-Pomona

"I often get the discouraging complaint by students, 'I don't know where to start in solving problems.' I think your systematic approach, a clearly laid-out strategy, can only help."

-Stephane Coutu, The Pennsylvania State University

Problem-Solving Method

Solved Problem

The book's numbered **Solved Problems** are fully worked problems, each consistently following the seven-step method described in Chapter 1. Each Solved Problem begins with the Problem statement and then provides a complete Solution:

- THINK: Read the problem carefully. Ask what quantities are known, what quantities might be useful but are unknown, and what quantities are asked for in the solution. Write down these quantities, representing them with commonly used symbols. Convert into SI units, if necessary.
- SKETCH: Make a sketch of the physical situation to help visualize the problem. For many learning styles, a visual or graphical representation is essential, and it is often necessary for defining variables.
- 3. RESEARCH: Write down the physical principles or laws that apply to the problem. Use equations that represent these principles and connect the known and unknown quantities to each other. At times, equations may have to be derived, by combining two or more known equations, to solve for the unknown.

SOLVED PROBLEM 6.6 Power Produced by Niagara Falls

PROBLEM

Niagara Falls pours an average of $5520\,\mathrm{m}^3$ of water over a drop of $49.0\,\mathrm{m}$ every second. If all the potential energy of that water could be converted to electrical energy, how much electrical power could Niagara Falls generate?

SOLUTION

The mass of one cubic meter of water is 1000 kg. The work done by the falling water is equal to the change in its gravitational potential energy. The average power is the work per unit time.

SKETCH

A sketch of a vertical coordinate axis is superimposed on a photo of Niagara Falls in Figure 6.22.

RESEARCH

The average power is given by the work per unit time.

$$\overline{P} = \frac{W}{A}$$
.

The work that is done by the water going over Niagara Falls is equal to the change in gravitational potential energy,

$$\Delta U = W$$
.

The change in gravitational potential energy of a given mass m of water falling a distance h is given by

$$\Delta U = mgh$$
.

SIMPLIFY

We can combine the preceding three equations to obtain

$$\overline{P} = \frac{W}{t} = \frac{mgh}{t} = \left(\frac{m}{t}\right)gh$$

Continued—