# Conquering the Physics GRE

## Third Edition

The Physics GRE plays a significant role in deciding admissions to nearly all US physics Ph.D. programs, yet few exam-prep books focus on the test's actual content and unique structure. Recognized as one of the best student resources available, this tailored guide has been thoroughly updated for the current Physics GRE. It contains carefully selected review material matched to all of the topics covered, as well as tips and tricks to help you solve problems under time pressure. It features three full-length practice exams, revised to accurately reflect the difficulty of the current test, with fully worked solutions so that you can simulate taking the test, review your preparedness, and identify areas in which further study is needed. Written by working physicists who took the Physics GRE for their own graduate admissions to MIT, this self-contained reference guide will help you achieve your best score.

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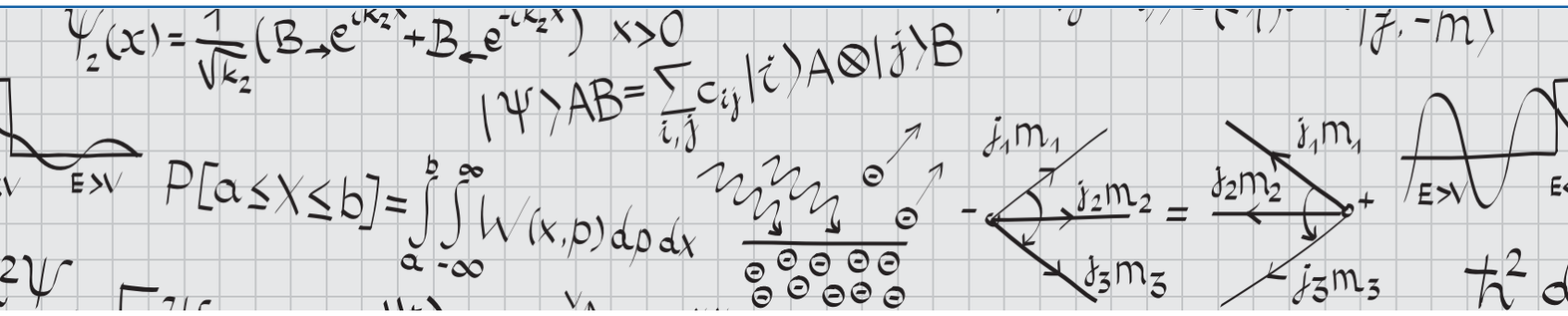

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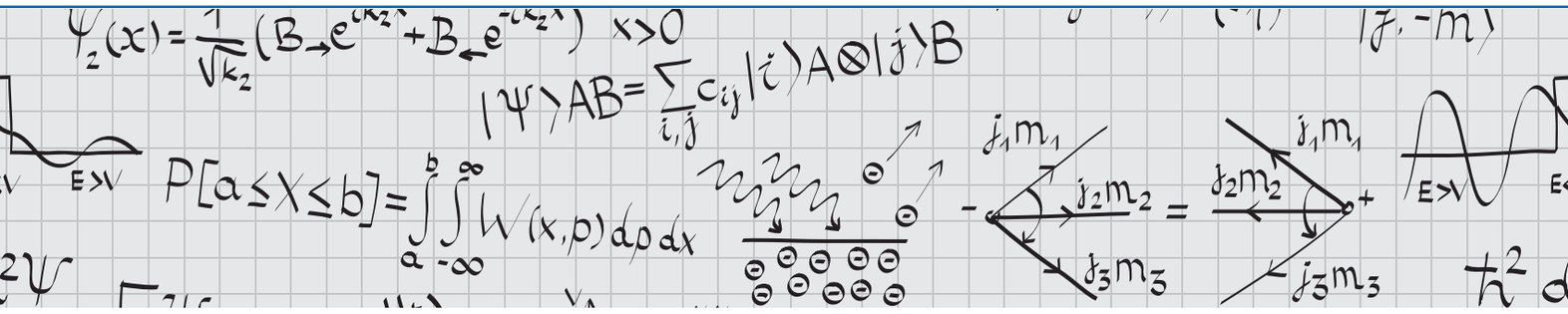


# PREFACE

*Conquering the Physics GRE* represents the combined efforts of two MIT graduate students frustrated with the lack of decent preparation materials for the Physics GRE subject test. When we took the exams, in 2007 and 2009, we did what any student in the internet age would do – searched the various online bookstores for "physics GRE prep," "physics GRE practice tests," and so on. We were puzzled when the only results were physics practice problems that had nothing to do with the GRE specifically or, worse, GRE practice books having nothing to do with physics. Undeterred, we headed to our local brick-and-mortar bookstores, where we found a similar situation. There were practice books for every single GRE subject exam, except physics. Further web searches unearthed www.grephysics.net, containing every problem and solution from every practice test released up to that point, and www.physicsgre.com, a web forum devoted to discussing problems and strategies for the test. We discovered these sites had sprung up thanks to other frustrated physicists just like us: there was no review material available, so students did the best they could with the meager material that did exist. This situation is particularly acute for students in smaller departments, who have fewer classmates with whom to study and share the "war stories" of the GRE.

This book endeavors to fix that situation. Its main contribution is a set of three full-length practice tests and fully worked solutions, designed to be as close as possible in style, difficulty, content distribution, and format to the actual GRE exam. We have also included review material for all of the nine content areas on the Physics GRE exam: classical mechanics, electricity and magnetism, optics and waves, thermodynamics and statistical mechanics, quantum mechanics, atomic physics, special relativity, laboratory methods, and specialized topics. To our knowledge, this is the first time that reviews of standard undergraduate subjects such as classical mechanics and thermodynamics have been paired with less standard material such as laboratory methods in the same text, specifically focused on aspects of these subjects relevant for the GRE. Exam-style practice problems and worked solutions are included for each review chapter, giving over 150 additional GRE-style practice problems in addition to the 300 from the exams. The shorter chapters have review problems at the very end, while the longer ones have review problems distributed throughout the chapter.

The chapter on quantum mechanics and atomic physics is the longest, for two reasons: the combination of these two topics makes up nearly 25% of the exam, and the formalism of quantum mechanics is so different from the rest of the physics topics covered on the GRE that we felt it worthwhile to discuss a number of calculational shortcuts in detail. Unique to our book is a chapter on special tips and tricks relevant for taking the GRE as a standardized multiple-choice test. Some of the standard test-taking wisdom still applies, but we have found that the structure of the multiple answer choices often provides valuable hints on how to solve a problem: you will not find this information in any other test-prep book, because it is based on techniques such as dimensional analysis and back-of-the-envelope estimation, which most test-prep authors (who are not physicists) are simply unaware of.

Next, a brief word on what this book is *not*. This is not a detailed review of undergraduate physics: many of the more difficult subjects get an extremely abbreviated treatment, designed to highlight only those formulas and problem types relevant for the exam. We believe this will help you succeed on the Physics GRE, but if any of the standard subjects are completely unfamiliar to you, please do *not* try to teach them to yourself from our book. There are many excellent texts out there relevant for that purpose, and we have included a list of them in the Resources section following this preface. We strongly encourage you to consult these references, as we have found them useful both in writing this present text and

in our careers as active physics researchers. We will often refer to them throughout the review chapters.

Last, a comment on the structure of this book. We realize that there are many, *many* equations to learn that are relevant for GRE-style physics problems. To keep the amount you feel you have to memorize to a minimum, we only assign equation numbers to equations we feel are important to remember – everything else you can safely ignore. (This is not to say that you should *memorize* every single numbered equation – Chapter 9 contains useful advice for what to memorize and what to derive.) Also, while most of the review chapters review material in roughly the order it was presented when you first learned it, Chapter 1 is structured very differently. We assume that you still remember many of the basic facts of classical mechanics from your freshman year introductory physics course, and so we focus our attention on *problem types* that are standard on the GRE, rather than on specific subtopics. We hope you will find this approach useful.

A book like this could never have been written without the help and support of other people. We especially thank Yichen Shen for his useful contributions to the condensed matter section of the Specialized Topics review. We thank Jen Sierchio and other members of the physicsgre.com community, as well as Raghu Mahajan, Nate Thomas, Jaime Varela, and Dustin Katzin at MIT, who proofread an early version of our first sample exam. Thanks also to Alex Shvonski, Kevin Satzinger, Jasen Scaramazza, Alastair Heffernan, Rizki Sharif, Benjamin Blumer, Andrew Ochoa, Ryan Janish, and especially Vinay Ramasesh for proofreading the first public versions of the sample exams and providing useful feedback. Y.K. would like to thank his advisor, Jesse Thaler, for bearing with him while working on a project that siphoned valuable time away from research. A.A. thanks Y.K. for being so accommodating and flexible toward his occasional "vanishing acts" from writing to attend to research obligations. A.A. also thanks his advisor, Enectalí Figueroa-Feliciano, and many other collaborators too numerous to name, for accepting (or at least pretending not to notice) any drag that this project caused on his research productivity.

Although we have made every effort to eliminate all factual and typographical errors from this book, the long errata lists for any physics textbook speak to the fact that this is impossible, especially in a first edition. If you find any mistakes of any kind, please email us at physics@physicsgreprep.com and let us know. Even the smallest of typos is worth fixing. We will be compiling an errata list on our website, www.physicsgreprep.com, which we will update on a regular basis. If you would like to receive information on errata as we find them, please email us. We also would greatly appreciate any feedback on this book, both positive and negative, as we strive to improve its usefulness for students everywhere.

Yoni Kahn and Adam Anderson

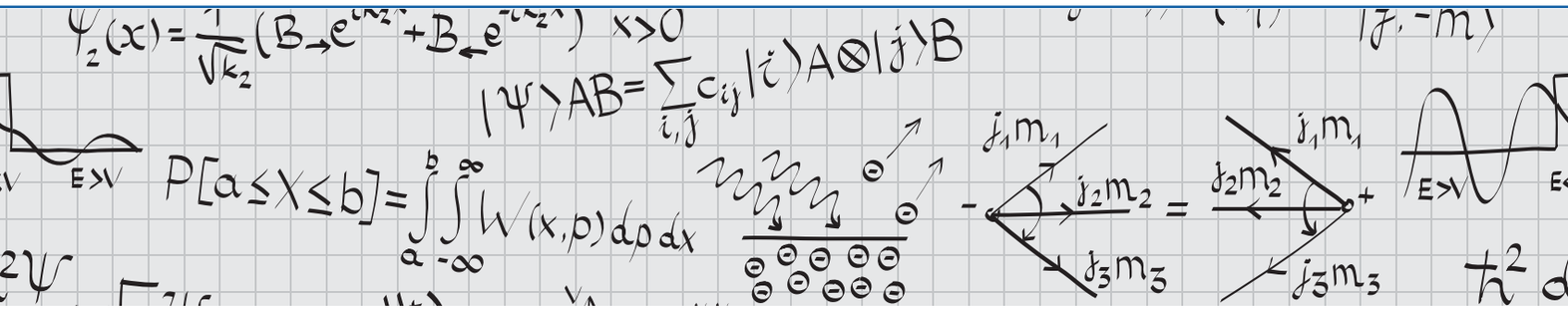
## Preface To The Third Edition

Since *Conquering the Physics GRE* was first published, both authors have completed graduate school and gone on to careers in academia: Yoni as a theoretical particle physicist, and Adam as an observational cosmologist. If this kind of career path is what you're hoping for, this is the book for you! *Conquering the Physics GRE* remains the only comprehensive reference book specifically tailored to the topics on ETS's Physics GRE, and indeed we often refer to this book as a quick reference for key undergraduate physics topics.

The revised third edition, published by Cambridge University Press, makes numerous changes in response to comments from students and faculty who have used this book for GRE preparation. Most importantly, the three full-length sample exams have been completely reworked so that the difficulty and types of questions better match the current content of the exam. We have added an equation index, a subject index, and a problems index so you can easily look up particular terms or concepts that appear on practice problems and solutions as well as in the review material. Finally, we have made many improvements to the review chapters, including additional figures, diagrams, and practice problems; an updated Nobel Prize section; and brand-new review problems for the Tips and Tricks chapter. We hope that these changes make this book a better reference not only for the GRE but for your bookshelf in your future physics career.

We are thankful to the many people who have made this revised edition possible, including Vince Higgs, Lucy Edwards, and Esther Migueliz at Cambridge University Press, and Lia Hankla, Sean Muleady, and Ahmed Akhtar at Princeton for proofreading. We also thank the many students who submitted errata for previous editions and suggestions for topics that now appear in this book.

Yoni Kahn and Adam Anderson

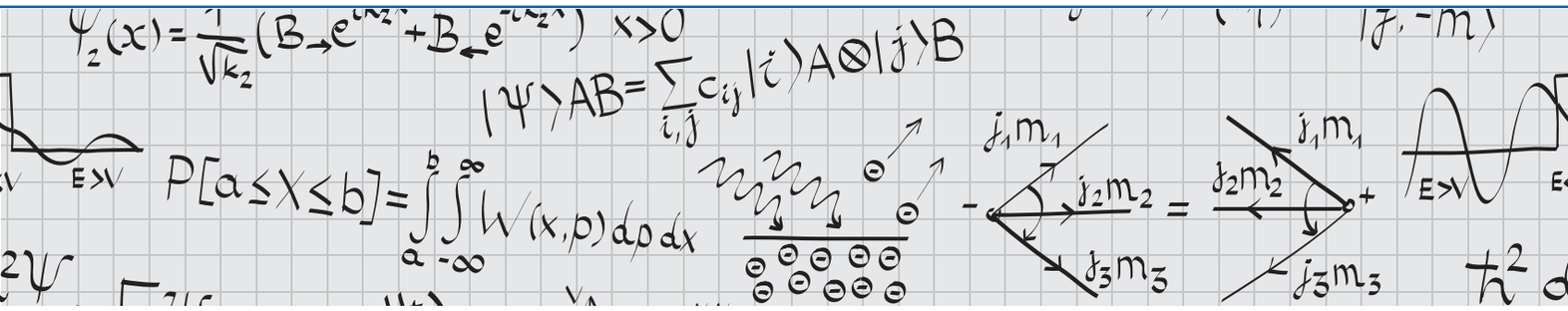


# HOW TO USE THIS BOOK

Studying for the GRE can be overwhelming! This book is long because it contains all the information you need to ace the exam, but not every student needs to study every chapter in equal detail. Here are some suggestions for how to use this book.

- **Only numbered equations are worth remembering.** The Physics GRE is a test of outside knowledge, so some memorization is inevitable. However, we have made a concerted effort to separate equations that are only used in specific worked examples from equations that are worth remembering for the test. Only the equations worth remembering are given equation numbers and are included in the Equation Index at the back of the book along with the page number where they appear; anything else you can safely forget for test day. This is still quite a long list, so rather than memorize each equation, check out Chapter 9 for suggestions on how to reduce your memorization workload by deriving more complex equations from more basic ones.
- **Use these sample exams as diagnostics.** ETS has released precious few actual GREs, and only the most recent (from 2001, 2008, and 2017) are representative of the current content of the test. We strongly suggest you leave the ETS exams until shortly before the actual test, where you can take them under simulated test-taking conditions. To start your studying, consider taking one of the sample exams provided in this book as a diagnostic, and note which areas you need to review the most. You can then focus on the review chapters covering these particular subject areas. Once you feel you've sufficiently filled in the gaps in your knowledge of undergraduate physics, you can take another sample exam and track your improvement, leaving the last exam for extra practice a week or two before the test, should you need it. Because we don't have access to ETS's proprietary scoring formula, we do not attempt to offer any conversion between raw score and scaled score (200–990) for our sample exams. Guessing at a formula would be extremely misleading at best, so use your score on our exams only as an estimate, but by all means use the ETS-provided conversion charts when taking the ETS exams.
- **Don't try to learn all of undergraduate physics from our book.** We have tailored the length and content of each of our review chapters to roughly follow the proportions of the GRE: 20% classical mechanics, 18% electromagnetism, 9% optics and waves, 10% thermodynamics and statistical mechanics, 22% quantum mechanics and atomic physics, 6% relativity, 6% laboratory methods, and 9% specialized topics. Our expositions of standard first- and second-year undergraduate topics are extremely brief or nonexistent, and we have given slightly more weight to more unfamiliar topics you're unlikely to find together in a single book, in order to make this book self-contained. If you find yourself totally mystified by a topic or completely unfamiliar with a formula, look it up in a more detailed reference! We've provided a list of suggested resources below.
- **Treat the end-of-chapter or end-of-section problems as subject practice rather than actual exam questions.** While our review problems follow the GRE multiple-choice format and don't require calculators, we don't intend them to exactly replicate GRE questions in style and difficulty: that's the purpose of the sample exams. Rather, the problems are there to highlight important problem types or calculational shortcuts, and as a result may feature solutions with more steps than you would see on test day. We recommend you work these problems as you're studying a particular chapter, but don't feel the need to keep to the GRE time limit of under two minutes per question.

Best of luck studying!



# RESOURCES

Here we collect all the texts we recommend and will refer to in the review chapters. If you're wondering why books by Griffiths show up so often, it's likely because he was on the question-writing committee for the Physics GRE several years ago. Anecdotally, we know that questions are recycled *very* often (which is why so few exams have been released), so it's likely that many of the questions you'll see on your exam were written by Griffiths or consciously modeled after his books.

- **Classical Mechanics:** Whatever book you used for freshman physics should suffice here. For a more in-depth review of advanced topics, try *Classical Dynamics of Particles and Systems* by S.T. Thornton and J.B. Marion.
- **Electricity and Magnetism:** D.J. Griffiths, *Introduction to Electrodynamics*. This book covers everything you'll need to know about electricity and magnetism on the GRE, *except* for circuits. For circuits and a review of the most basic electricity and magnetism problems, which Griffiths glosses over, consult any standard freshman physics textbook. A good treatment of electromagnetic waves can also be found in R.K. Wangsness, *Electromagnetic Fields*. E. Purcell, *Electricity and Magnetism* is an extremely elegant introduction emphasizing physical concepts rather than mathematical formalism, should you need to relearn the basics of any topic. Under no circumstances should you consult Jackson! It's far too advanced for anything you'll need for the GRE.
- **Optics and Waves:** Like classical mechanics, nearly all the relevant information is covered in your freshman physics textbook. Anything you're missing can be found in the relevant chapters of *Introduction to Electrodynamics* by Griffiths.
- **Thermodynamics and Statistical Mechanics:** No overwhelming recommendation here. *Thermal Physics* and *Elementary Statistical Physics* by C. Kittel, or *Fundamentals of Statistical and Thermal Physics* by F. Reif, are decent. *Statistical Physics*, by F. Mandl has some decent pedagogy and the nice feature of many problems with worked solutions. Fermi's *Thermodynamics* is a classic for the most basic aspects of the subject.
- **Quantum Mechanics and Atomic Physics:** D.J. Griffiths, *Introduction to Quantum Mechanics*. This is really the only reference you need, even for atomic physics questions. Shankar and Sakurai are serious overkill, stay away from them for GRE purposes!
- **Special Relativity:** Chapter 12 of *Introduction to Electrodynamics* by Griffiths, and Chapter 3 of *Introduction to Elementary Particles*, also by Griffiths, for more examples of relativistic kinematics. Note that, confusingly, the two books use different sign conventions, so be careful!
- **Laboratory Methods:** For advanced circuit elements, *The Art of Electronics* by P. Horowitz and W. Hill is a classic, and used in many undergraduate laboratory courses. An excellent general reference for radiation detection is *Radiation Detection and Measurement* by G.F. Knoll. Chapter 1 covers general properties of radiation, Chapters 2 and 4 cover interactions of radiation with matter, Chapter 10 covers photon detectors, and Chapter 3 covers precisely the kind of probability and counting statistics you'll be asked about on the GRE. The rest of that book goes into far more detail than necessary, so don't worry about it. For lasers, try O. Svelto, *Principles of Lasers*, Chapters 1 and 6.
- **Specialized Topics:** The first chapter of D.J. Griffiths, *Introduction to Elementary Particles*, is a *mandatory* read. It seems that every GRE in the last several years has contained at least one question that can be answered purely by picking facts out of this chapter. The rest of the book is pretty good too, but the later chapters are almost certainly too advanced for the GRE. For condensed matter, try *Introduction to Solid State Physics* by C. Kittel, or Chapters 1–9 of *Solid State Physics* by N. Ashcroft and N. Mermin for a more advanced treatment written in a friendly and accessible style.

- **All-around:** L. Kirkby's *Physics: A Student Companion* is a nice all-around summary of a wide range of physics topics. It's geared toward students studying for exams, so it is concise and more distilled than the subject-specific books.

There are also several useful websites containing information related to the Physics GRE:

- www.grephysics.net: A compilation of the 400 problems released by ETS prior to 2011, and student-contributed solutions.
- www.physicsgre.com: A web forum for discussion of issues related to the GRE, and the grad school application process in general. Highly recommended: one of us (Y.K.) met several future colleagues on this forum before meeting them in person.
- www.aps.org/careers/guidance/webinars/gre-strategies.cfm: A webinar on Physics GRE preparation given by one of us (Y.K.) for the American Physical Society, drawing on strategies discussed in this book.