Advice After Introductory Physics

I've met lots of people who have self-studied calculus-based physics, want to learn more, and are unsure what to do next. This document lists some resources for going further. If you want advice for how to start out learning physics or doing physics competitions, see my introductory advice file.

Deepening Core Knowledge

You're done with the introductory material after finishing a book like Halliday, Resnick, and Krane, which roughly corresponds to the MIT courses 8.01 and 8.02. See the final exams for these courses if you want to check. If you enjoyed what you learned, there are many ways to deepen your knowledge.

- To get a deeper understanding of mechanics, try the books by Kleppner and Kolenkow (1st edition) or Morin. These are used for honors introductory physics at MIT and Harvard, respectively. There's substantial overlap between the two, so just look at both and see which you like better. Morin has more sophisticated but less realistic problems. Morin's problems are about frictionless planes and massless strings, while Kleppner's problems are about cars and rockets.
- Halliday, Resnick, and Krane's brief coverage of relativity probably isn't enough to confidently handle Olympiad problems on the subject. You can learn more about the subject in the last few chapters of either Kleppner and Kolenkow or Morin. I think Morin's discussion of relativistic kinematics is excellent, carefully resolving many of the confusions a beginner might have.
- To get a deeper understanding of electromagnetism, try *Electricity and Magnetism* (3rd edition) by Purcell and Morin, used for honors introductory physics at Princeton. It has many insightful problems, but it's best known for using relativity to introduce magnetism, in the brilliant chapter 5. For a short and sweet introduction to vector calculus that complements the book, try Schey's *Div, Grad, Curl, and All That*, which has good pictures.
- The waves and thermodynamics chapters in Halliday, Resnick, and Krane are enough to get started on competitions, but other books can help deepen your understanding. For a clear introduction intended explicitly for Olympiad preparation, try the first and second volumes of *Competitive Physics*, by Wang and Ricardo, respectively.
- If you prefer video lectures to books, there's an exceptional amount of good content on MIT OCW. The classic lectures by Walter Lewin for 8.01 (mechanics) and 8.02 (electromagnetism) are mathematically elementary, but have many interesting physical examples. Multivariable and vector calculus is covered very clearly in 18.02. For waves, see either Lewin's 8.03 lectures or the newer OCW version.
- It's also very rewarding to get a broad overview of physics as an intellectual tradition. I strongly recommend the *Feynman Lectures on Physics* for fascinating discussion from a master of the subject. If you're interested in the history behind the material in an introductory physics course, try *Understanding Physics* by Cassidy, Holton, and Rutherford.
- I generally recommend against reading any book with a title like "Modern Physics." These books have the same problem as algebra-based physics textbooks: they try to explain too much with too little. Equations that should be derived with two lines of math end up "motivated" with hundreds of words of vague argumentation. Since modern physics courses need to have a large

bank of problems to test students with, but they don't teach the students to derive anything, the textbooks end up packed with thousands of joyless, cookie-cutter questions where you simply look up numbers in a table and plug them into a given formula. In my opinion, a standard introductory book such as Halliday, Resnick, and Krane already gives enough background on modern physics for the Olympiad. But if you really want to jump into these topics early, Krane's *Modern Physics* is well-written and comprehensible.

There are many resources out there, but don't get too worried about choosing one. All good books contain the same essential core. As long as you understand the resource you're using, and you're learning new things, you're on the right track. If you're not sure whether you can or should start a book, just read the first chapter and see how it feels!

Competition Practice

There are many good sources of practice problems for competitions.

- Your primary source should be past USAPhO exams. I've rewritten the solutions to these exams for clarity, but make sure to give each problem your best try before peeking; it's easy to waste one that way. If you find any errors, email me!
- If you run out of practice USAPhOs, AAPT sells a CD-ROM of USAPhO exams going back to 1997. You can ask your physics teacher to purchase this.
- Many problem sources are listed in the Syllabus for my tutoring program, but my favorite are:
  - Jaan Kalda's study guides. These are exceptional because they pair problems with the specific ideas needed to do them, allowing for rapid progress. They leave a lot to the reader; you won't get far if you don't already know calculus-based physics well. Student-written solutions are available here.
  - 200 Puzzling Physics Problems. This is a set of entertaining and devilishly tricky problems, mostly compiled from Eastern European physics competitions. (However, I don't recommend using this as your main source of practice. A number of problems rely on obscure tricks. It's best when used as food for thought.)

More Advanced Physics

There's also a lot you can do if you want to move towards more advanced physics.

- First, a warning. At this level, you'll see a lot of "study guide" books marketed as "student friendly", "for students", or even "for dummies". They all have glowing reviews[1], but I strongly recommend against using them. They don't explain how the physics works; they just tell you the mechanical steps you need to remember to solve the simplest exam problems.

  In a course, they can be a life saver if you're pressed for time and mostly interested in grades, but the superficial understanding you'll get from them will collapse by the first lecture of the next course. It's like building the facade of a house without the foundation. If you're self-studying, there's no reason to ever use these books, because you have the time to do it right.

[1] These reviews are especially dangerous because they make it hard to differentiate quality. For example, A Student's Guide to Maxwell's Equations is decent, but A Student's Guide to Lagrangians and Hamiltonians is atrocious: its notation goes undefined and its derivations are just wrong. Every month I see a nonsensical StackExchange question from a poor student who's been terribly misled by the latter book. But both have a hundred five-star ratings online.

- If you're following a standard college curriculum, the next thing to do is to get an understanding of waves and oscillations. This corresponds to the MIT course 8.03, with further background given in the course 18.03 on Differential Equations. For a textbook reference, *Vibrations and Waves* by French is short and clear, covering the essentials of the subject, while *Waves* by Crawford is more thorough, with many interesting real-world applications and home experiments. If you enjoyed Morin's style, you can also try his *Waves* book draft.

- For intermediate electromagnetism, the best book is *Introduction to Electrodynamics* by Griffiths, by a big margin. The book is very clear, and its problems get surprisingly deep, due to Griffiths' experience writing many papers on the subtleties of classical electromagnetism. This level of electromagnetism requires deeper familiarity with vector calculus, which you can pick up from the first few chapters. For a dedicated introduction to the math, see David Tong's notes on Vector Calculus for a clean approach that gets to tensors[2] and introduces index notation, a powerful tool for deriving more complicated vector calculus identities.

- After learning mechanics at the level of Morin or Kleppler and Kolenkow, you can start learning Lagrangian and Hamiltonian mechanics, which are typically not useful for the Olympiad, but extremely important for physics in general. For a clear and gentle introduction, see *Classical Mechanics* by Taylor. For a nice complement, see David Tong's notes on Dynamics. (If you completed Morin, the problems in these more advanced resources will be a piece of cake.)

- For intermediate thermodynamics, I recommend either *Concepts in Thermal Physics* by Blundell and Blundell, or *Thermal Physics* by Schroeder. Blundell and Blundell is more comprehensive, with many interesting sidenotes and applications; Schroeder is very clear and crisp.

- After learning about waves and differential equations, you could start introductory quantum mechanics, from the wave mechanics perspective. The most common book with the lowest prerequisites is *Introduction to Quantum Mechanics* by Griffiths, which comes with clear explanations and great problems. However, many complain the book uses too little math, hiding the essential structure of quantum mechanics behind elementary but messy derivations. For video lectures at a similar level, try the 8.04 lectures by Barton Zwiebach (more clear) and Allan Adams (more energetic).

- To get a deeper understanding of quantum mechanics, you're going to need to learn linear algebra. The book *Introduction to Linear Algebra* by Strang, used for 18.06 at MIT, is excellent for this. You might not see why linear algebra would be useful, given how it's glossed over in high school, but you'll probably use linear algebra constantly throughout your life, possibly even more than calculus, even if you don't go into physics!

- If you want a deeper introduction to quantum mechanics, that uses linear algebra freely, try *Principles of Quantum Mechanics* by Shankar, or the 8.05 lectures. Alternatively, if you have

[2]By the way, tensors are another one of those topics where you need an "official" source, like a book chapter or a polished set of lecture notes. When I google "introduction to tensors", most of the first ten results are terrible for beginners. I recognize a few that once got me confused for days, because they were full of typos, and cross-checking them made things worse because they used incompatible conventions. Others are correct, but way too sophisticated to serve as a real introduction. It doesn't help that mathematicians, computer scientists, engineers, and physicists all mean different things when they say "tensor"! Don't try to brute force learning this kind of thing by opening twenty tabs. Just use one good source and stick with it. Exploring will deepen your knowledge only once you have the foundation set.

less physics background, consider Umesh Vazirani's Quantum Computation course. Quantum computation is a great place to start because it uses all the weirdest features of quantum mechanics, without the distraction of solving complicated differential equations.

- If you want to start heading towards general relativity, the two gentlest books are *Gravity* by Hartle and *A First Course in General Relativity* by Schutz. While both cover similar ground, Schutz puts all the mathematical background up front (including a great introduction to four-vectors and tensors), while Hartle starts with physical results, having you take some of the math on faith until it's filled in later.

- If you're interested in fancy stuff like quantum field theory or string theory, I generally *don't* recommend reading anything about it at this stage. String theory in particular has an enormous amount of prerequisites, which means that books which try to popularize it skew towards "mindblowing" metaphysics. These books are built on layers of analogies, and you'll naturally want to probe deeper. But the second you try, the analogies will fall apart, because that's all they are. On the internet you'll find many lost souls who have taken the analogies too literally, arriving at homemade theories that have little to do with anything in physics.[3]

  Anyway, if you're determined to get a taste of these subjects, I recommend resources with at least a few equations in them. For example, in ascending order of difficulty:

  - Cumrun Vafa's *Puzzles to Unravel the Universe* is like a popular string theory book, but with points explained with neat mathematical puzzles. It's meant for freshmen at Harvard, which means you only need high school algebra to understand it.
  - David Tong's Particle Physics lecture notes cover the basics of the Standard Model and beyond, with many references to the history and deeper theory, and only high school math.
  - Leonard Susskind's Theoretical Minimum lectures cover graduate-level topics using just calculus. They're not nearly detailed enough to serve as a foundation, but they do a great job of giving the flavor of the logic.
  - Griffiths' *Introduction to Elementary Particles* clearly explains the basics of particle physics and the structure of the Standard Model, along with how to do some toy calculations in quantum field theory. It requires a good understanding of undergraduate quantum mechanics and special relativity.
  - Barton Zwiebach's *A First Course in String Theory* is the string theory textbook with the least prerequisites, and it actually derives many of the results it uses. It also requires undergraduate quantum mechanics and special relativity.

  Don't get too confident if you use these – they only cover a small fraction of what typical introductory books in these subjects do. To really get started in these fields, you should at minimum learn graduate-level quantum mechanics first, at the level of Sakurai. For more advanced resources for each subfield of physics, see the introductory pages of my lecture notes.

[3] And it's easy to go astray even if you have excellent reading comprehension, because English is ambiguous. For example, if nothing is better than ice cream, and licorice is better than nothing, is licorice better than ice cream?

Second Opinions

The internet has some great sources for physics learning advice, and unfortunately many not-so-great sources. There are two main reasons advice can be bad. The first is that many study guides are written by people who have never actually learned the basics. They write guides because it takes less effort to compile a big list of books and *imagine* knowing what's in them than to open a single book and *actually* learn something. The second is that most of the remaining study guides are written by eminent professors who haven't read an undergraduate-level book in decades. They're not going to start doing that again, so they tend to recommend outdated books that worked for them forty years ago. Or, worse, they simply skim through a newer book's table of contents and recommend it if the chapter titles and the author's name sound familiar; this way of doing things keeps a lot of subpar books on the market. The basic rule is that you should only believe a book recommendation if it was written from somebody who actually read and understood the book.

With that out of the way, here are links to some often-cited internet resources.

- Chicago Undergraduate Physics Bibliography. This is a list of books aimed towards learning theoretical particle physics. It has solid advice, but it's also 20 years out of date and missing many of the canonical books.

- How to Learn Math and Physics. This list, oriented towards mathematical physics, is also 20 years out of date. It has great books on the list, but it could be difficult to use for a self-learner because fluffy, equation-free popular books are placed right next to advanced graduate texts; undergraduate level books are almost absent.

- How to become a GOOD Theoretical Physicist. Gerard 't Hooft was one of the giants of particle physics. About 20 years ago, he compiled a massive list of resources available around the internet at the time. Unfortunately, the list was never finished or updated. Now, half the links are broken, and the rest point to rough drafts of lecture notes that are honestly subpar, even compared to other free resources. It's constantly recommended because its length and author are impressive, but as far as I know, nobody has ever actually used it.

- So You Want to Learn Physics.... Susan Rigetti's book list is much more useful than the others here, because she understands how it felt to be a student. This list covers a full undergraduate and graduate education, based on the canonical books.

- So You Want To Be A Physicist. This is a huge resource that covers everything about the process of becoming a physicist in the US, from high school to postdoc applications. There's not much on the learning process itself, but it's helpful, especially if you're coming from outside physics or outside the US.

- A Physics Booklist. Once upon a time, the internet was arranged around discussion forums, the greatest of which was sci.physics. It died a slow, but natural death 20 years ago as crackpots came in and people who actually knew things quit in exasperation. This unhelpfully long list is one of the relics of this lost civilization.

- Book Recommendations. I help curate this massive list of lists of book recommendations on Physics StackExchange, which is the closest thing to a successor of sci.physics. It's many times larger than all the other lists here combined, but that also means it has a lot of cruft.