Advice After Introductory Physics

Over the years I've met a lot of high schoolers 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.
- For a concise introduction to mechanics that's written in the style of more advanced physics classes, see David Tong's notes on Dynamics. All of Tong's notes are great for further study.
- 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 relativity, see the first few chapters of *A First Course in General Relativity* by Schutz, which also contains a nice introduction to tensors.
- To get a deeper understanding of electromagnetism, try *Electricity and Magnetism* (3rd edition) by Purcell and Morin, used for honors introductory physics at many universities. It has good problems, at just the right level for somebody coming from an introductory course. It's best known for using relativity to introduce magnetism; chapter 5 is a pedagogical masterpiece.
- The thermodynamics covered in Halliday, Resnick, and Krane is more than enough for all competitions, but for a deeper understanding, I recommend *Concepts in Thermal Physics* by Blundell and Blundell. It also applies the theory to many topics in modern and applied physics.
- If you prefer lectures to books, there's an exceptional amount of good content on MIT OCW. The classic references are the 8.01 (mechanics) and 8.02 (electromagnetism) lectures by Walter Lewin, which are mathematically elementary, but which have many interesting physical examples. Also see the 8.03 (waves) lectures, and the accompanying problem solving recitations. If you've ever wanted to start learning quantum mechanics, try the 8.04 lectures by Barton Zwiebach (more clear) and Allan Adams (more energetic).
- 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 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. If you want more, your next exposure to it should be from a source which actually derives the equations it uses, such as a quantum mechanics textbook.

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.

- To get a general sense of what's out there, you can read the introductory pages of my lecture notes, which list many of the subfields of physics and books for each one. Another good resource is Susan Fowler's book list, which documents her journey learning physics from scratch; all the books on her list are great choices.
- If you didn't do it while learning electromagnetism, you'll want to get a grasp on multivariable calculus, which is used everywhere in physics. An excellent resource is the MIT course 18.02.

- 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. The short book *Vibrations and Waves* by French is especially good.

- You can also jump to mid-college courses on mechanics and electromagnetism, from books such as *Classical Mechanics* by Taylor and *Introduction to Electrodynamics* by Griffiths, corresponding to the MIT courses 8.223 and 8.07. However, I think a wiser option is to use the intermediate books listed above as a stepping stone.

- After learning the material of 8.03, you could learn introductory quantum mechanics, from the wave mechanics perspective. The most common book with the lowest prerequisites is *Introduction to Quantum Mechanics* by Griffiths.

- To get a deep 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 an introduction to quantum mechanics that uses your linear algebra knowledge, 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. Or, if you want an introduction to quantum mechanics in general, try *Principles of Quantum Mechanics* by Shankar.

- If you're interested in fancy stuff like string theory, I *don't* recommend reading anything about it during high school. String theory in particular has an enormous amount of prerequisites, which means that books which try to popularize it degenerate into incomprehensible babble. If you're a bright high schooler totally 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.
  - Leonard Susskind's Theoretical Minimum lectures cover graduate-level topics using just algebra and a little 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.
  - 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. (However, it still requires almost every other book listed in this document as a prerequisite, and its first 300 pages barely cover the first 30 pages in a typical string theory book.)

Many more resources are listed in the Book Recommendations thread on Physics StackExchange. If this all sounds overwhelming, don't worry! The first book you read in a subject is always the hardest. None of these books will take half the time to read that your first introductory book did.