Advice For Introductory Physics

In this file I answer some frequently asked questions about learning physics and entering physics competitions. For advice for how to continue after finishing introductory physics, see this file.

Preliminaries

What should I know before I start learning physics?

In the American system, people typically learn physics in two stages. First, they take a year-long algebra-based introductory course, which covers all subjects (mechanics, electromagnetism, thermodynamics, a hint of modern physics), typically given in 10^{th} or 11^{th} grade, and corresponding to AP Physics 1 and 2. Those interested in learning more typically take a second, calculus-based introductory course, covering mechanics and electromagnetism, corresponding to AP Physics C.

To succeed in an algebra-based physics course, you should have a good grasp of algebra and trigonometry, have good "number sense", and know how to read graphs. (In terms of formal courses, you should be taking Algebra II or higher at the same time.) If you don't have this stuff down cold (e.g. if you take more than one second to recall the value of $\sin 30°$), then everything will be much harder, because a two-step problem will *feel* like it's twenty steps, as you scramble to remember math you've half-forgotten. It's like trying to learn the guitar while hopping on one leg.

What should I know before I start entering physics competitions?

In America, about 3.5 million students graduate high school per year, 150,000 take AP Physics 1 (algebra-based mechanics), and 50,000 and 20,000 take the calculus-based AP Physics C mechanics and electromagnetism tests, respectively. About 6,000 students take the $F = ma$ exam, from which 400 students qualify for the US Physics Olympiad, 20 qualify for the training camp, and there 5 are selected to travel to the International Physics Olympiad.

For people coming from a math background, the most important thing to remember is that physics competitions aren't like math competitions. The typical American 10^{th} grader has taken ten years of math in school and *zero* years of physics. If you're a bright student that likes math, math competitions are a fun way of extending the knowledge you've spend a decade building – you already have the foundations set, and you can easily start by learning a few extra tricks.

If you've done well on math competitions, it's tempting to jump directly into physics competitions with the same attitude. After all, physics is just made of equations, which are math, right? If you haven't taken a solid year-long introductory physics course already, this attitude will make you crash and burn. It typically results in people memorizing big lists of equations without being able to answer the most basic conceptual questions, and making ridiculous mistakes like confusing tension T for time T because they're the same letter. Without introductory physics under your belt, you're in the same position as a 1^{st} grader is in math, trying to do a math competition without even knowing how to add.

Another important difference is the role of more advanced classes. Richard Rusczyk famously wrote in *The Calculus Trap* about how the standard math curriculum (calculus, multivariable calculus, linear algebra) often just teaches a few calculational skills, without emphasizing the problem solving skills needed in math competitions.

This is true, but physics is different. Math competitions focus on niche topics like Euclidean geometry which rarely come up in higher mathematics, but can be scaled up to arbitrary difficulty.

By contrast, physics competitions were invented to spark interest in physics, and to teach students to think like physicists. Climbing from the $F = ma$ exam to the IPhO will take you on a tour through some of its greatest ideas, from the ones that Newton pioneered to those behind recent Nobel prizes. A good theoretical physics graduate student should be able to solve IPhO problems, and that's a good thing – it means you're learning something real, not tricks made for a competition.

So if you've learned advanced topics like relativity and quantum mechanics on your own, don't hesitate to jump into competitions; you'll be rewarded for your experience. And if you find these subjects interesting and are debating whether they would be worth doing, just jump in! It's all good stuff, because it's physics, and physics is fun.

Resources

How can I start learning physics by myself?

You're in luck, because there are better resources for learning physics independently now than ever before! I'll list a few at the end of this answer. However, I want to start with some warnings. These days, it's easy to find good resources, but it's even easier to find bad resources, which always vastly outnumber the good, and you can end up wasting tons of time.

First, if you're just starting out, I *strongly* advise against using any resource that isn't designed as a cohesive whole, by a small group of experts. For example, the popular websites Brilliant and Expii have lots of neat problems. But at this point, their physics curricula aren't developed in a complete and logical manner. The problems have wildly different notation, conventions, and difficulty, and units tend not to be self-contained, often requiring knowledge from later units.

These issues apply doubly to learning from Wikipedia. It has a lot of useful information, but if you ever get confused reading it, e.g. if two definitions don't seem to be compatible, or if a step in a derivation doesn't seem right, you should never, ever try to resolve it by opening up twenty Wikipedia tabs. The answer is simply not going to be there, and you'll just magnify your confusion. The same goes for trying to learn by talking to a large language model. As of 2024, these systems are about as good as Wikipedia for getting the gist of a subject, but remain unsuitable for solving all but the simplest problems. (After all, they're trained on sources like Wikipedia!)

Popular videos tend to be even worse. On YouTube, there are millions of videos where some guy explains a physics topic off the top of his head. The problem is that most of these people have only learned the basics the previous day, often by skimming Wikipedia. Because they're just talking off the top of their heads, their videos tend to be vague, inaccurate, stuffed with filler, and way too long, since YouTube pays them by the minute. Sometimes students instinctively try to fix this by cranking the video speed up to 3x, which I think is almost always a mistake. If you ever get the urge to do this, it probably means the video carries too little new information to be worth watching.

When I was a kid, I always followed the procedure for information gathering taught to me in public school: Google the term, open the top ten links, and then open all the links in those pages. The typical result was that I'd get lost all day on an issue that should have taken five minutes, wondering in despair why somebody didn't just organize the material consistently. Only later did I realize that this is literally what books and courses are! In fact, in the cases where YouTube and Wikipedia explanations are complete and reliable, they've usually been copied line by line from a book. If the book is a source of illumination, these secondary resources are just the shadows it casts in various directions. The internet is certainly the world's greatest source of amusing pictures and videos, but it's not great for anything deep. All the physics resources and discussion published online, combined, contain less content than a few good bookshelves. Probably the best thing about the internet is that you can use it to find PDFs of such books.

Of course, books and courses also vary widely in quality, and it's important to avoid getting stuck on a poor one. To understand why, you have to consider how good textbooks are created in the first place. Usually, a teacher will start a course using an existing textbook. If they care enough, they'll consider a wide variety of approaches, then gradually synthesize a new one for their lectures, based on their preferences; perhaps it will be more modern, more mathematically rigorous, or more intuitive than the others. Then they'll start typing up lecture notes, and once those get refined enough, they can drop the textbook and have the students read the notes directly. Over many years, students will find errors and confusing spots in the notes, which the teacher fixes up, while accruing a large bank of classroom-tested, interesting questions from the annual problem sets and exams. Finally, the teacher staples all the materials together, and a new textbook is born. All of the books and courses I recommend in this document were made this way.

There are two active ingredients in the process. The first is the students, who act as dedicated test-readers, pushing the teacher to improve their materials year after year. Books that aren't student tested tend to be plagued with issues, such as constant typos, trivial or nonsensical problems, huge jumps in difficulty, and crucial omissions. The second is the teacher's deep expertise. To write a good book, the teacher must know far more than what is actually contained in the book. This lets them identify the big picture, understand problem solving strategies, create new problems, and see the limitations of the usual formulas. Without this kind of expertise, books can still be clear, but they'll be missing something. They'll tend to have lots of unoriginal plug-and-chug problems, rigid advice that only works on such problems ("never use rotating frames", "always begin by writing $F = ma$ for every particle"), and generalizations that don't actually hold in the real world.

Therefore, a reliable way to find good books and courses is to look for those that have been refined over a long period of time, by one or two professors, teaching a dedicated course at a good university. So now we can finally get to some course recommendations!

- If you would like to get started with algebra-based physics, a good first goal is to pass AP Physics 1/2. (Don't worry about the $F = ma$ exam yet.) Two good resources are the videos by Flipping Physics and Khan Academy, which have been thoroughly tested and refined by great teachers. If you'd like more structure, find an AP Physics course either online or in person nearby. If you're confident enough to study on your own, see the books recommended below.

- To learn calculus, you can get started with MIT OCW's 18.01 course. You can also go through any one of the nearly identical standard calculus books on the market, such as Stewart's, which all cover everything you need and more.[1]

- Once you know basic calculus, such as derivatives and single integrals, you're ready to start calculus-based physics. My top recommendation is Yale's Fundamentals of Physics courses.

[1] Mathematicians often complain that these books aren't rigorous enough, and prefer books like Spivak's. But these books are meant to train mathematicians, not physicists. Spivak is great for that purpose, but it only has a single chapter on actually performing specific integrals, and it starts with proving basic propositions like $0 < 1$ and $1 + 1 \neq 0$. If you're interested in that kind of thing, you can start reading Spivak without any prior calculus background. (Another good starting point is the Art of Problem Solving calculus book, which has a good balance of proof sketches and concrete problems.) However, you won't need *any* experience with rigorous proofs to get started in physics. After all, Newton didn't care about rigor when he invented calculus. When the mathematical foundations of calculus were finally set, physicists had already been using it to solve real problems for generations.

MIT OCW also has introductory physics courses, titled 8.01 and 8.02, but they have some drawbacks. Walter Lewin's old lectures are full of cool demonstrations, but they're short on theory; they would work better as a supplement if you're interested. Meanwhile, the current 8.01 course is broken up into 5 minute tidbits, which frankly makes it feel like a high school course to me, and the 8.02 course materials are incomplete. EdX used to have a lot of great free options, but they're mostly shut down now, as its new owners try to figure out how to make money from them, and I don't think the new ones are nearly as good.

The reason it's so hard to find good video lectures for introductory physics is that in the past decade, most top universities switched to teaching these courses with active learning, where lecture is replaced with group problem solving, and students do background reading at home. Education research has shown that this works better for the average student, who would zone out during traditional lectures, and learn nothing. If you're motivated enough to be self-studying, that probably doesn't apply to you, so you shouldn't feel bad about using lectures. But it does show that lectures aren't necessary, so you can do everything by just following good books and thinking hard.

What are some good introductory books at each level?

There's a robust ecosystem of physics textbooks, with many good options.

- For algebra-based physics, commonly used books are listed in AIP's survey of physics teachers. Some examples of decent books, in very roughly increasing order of difficulty, include:
  - Hewitt, *Conceptual Physics*.
  - Serway and Faughn, *Holt Physics*.
  - Serway and Vuille, *College Physics*.[2]
  - Cutnell, Johnson, Young, and Stadler, *Physics*.
  - Knight, Jones, and Field, *College Physics: A Strategic Approach*.
  - Giancoli, *Physics: Principles with Applications*.

  Judging from reviews and survey data, Hewitt is a good option for a typical high school course, while Giancoli is good for an honors high school course, such as for AP Physics 1 and 2. However, these books are all pretty similar, so you shouldn't worry if you happen to have a different one. None of these books are enough for physics competitions, but they'll set a good foundation. To start at this level, you should at least be simultaneously enrolled in an Algebra II math course. If you're comfortable with calculus, you could also just skip directly to calculus-based physics.

- For basic calculus-based physics, there are many books, such as the ones by Giancoli, Knight, Serway and Jewett, Tipler and Mosca, Young and Freedman, and Halliday, Resnick, and Walker. They all cover the same material, with nearly identical tables of contents, and they're all suitable for AP Physics C. Most of them have titles like "University Physics" or "Physics for Scientists and Engineers". They're polished and equally good, so just use whichever you can easily get.

[2] If you're confused about the title, note that there's substantial overlap between high school and college courses. Most people who take physics courses in college are taking algebra-based introductory physics, which ranges in difficulty between that of a typical high school course, and AP Physics 1 and 2. Similarly, most people who take math courses take "College Math", which is about equivalent to Algebra II. These types of courses are typically taken just to fulfill a graduation requirement, and don't usually lead to further physics and math courses. Most people who end up majoring in physics start in calculus-based introductory physics in college, which is discussed below.

- For more advanced calculus-based physics, I strongly recommend *Physics* (5th edition) by Halliday, Resnick, and Krane. This book is used in college honors courses, and has significantly more challenging problems. The explanations are very clear, and I know many people who have succeeded using it. I recommend starting here if you have some prior exposure, e.g. through a regular course or an AP Physics exam, and your calculus is good.

Like most physical things in America, introductory physics textbooks were built in the heady days of the 1950s. After Sputnik, concerned scientists and policymakers made a societal push for STEM education. This gave rise to many great books, such as the original Halliday and Resnick, and the Feynman lectures. Halliday and Resnick was the dominant calculus-based physics textbook in the 1960s, and things haven't changed much since then. Newer textbooks are direct descendants, sometimes taking topics out, but rarely adding new topics in. For example, Halliday and Resnick itself split into two versions, *Physics* and *Fundamentals of Physics*, by Halliday, Resnick, and Walker. The latter is essentially just *Physics*, but with the most advanced parts of each chapter removed.

When shopping for these books, you might notice that they come in many editions, and that the latest edition is much more expensive than the rest. For example, Serway and Jewett is on its 10th edition, while Young and Freedman is on its 15th. However, you shouldn't worry if you can't afford the latest edition, or if you happen to already have an earlier edition. The core introductory physics curriculum hasn't changed for decades; the real purpose of the endless editions is to keep money steadily flowing in for the publishers. To make a new edition, they randomly rearrange the ordering of the problems and the numbers inside, add a few janky "online-only" problems[3], and lobby university administrators to force their instructors to make their students buy it. In other words, the main purpose of new editions is to prevent students from buying cheap used copies.[4]

Of course, most of the time, you should prefer the latest edition of a book. They tend to have fewer mistakes, and sometimes better content; for example, in the case of Halliday, Resnick, and Krane, the latest (5th) edition has many very useful multiple choice questions, and some extra tricky problems. But these benefits don't apply for textbooks with over 10 editions, which just tend to get bloated with plug-and-chug problems and weird pictures. This is all just to say that while physics is certainly real, there are a lot of things about the physics education system that aren't. You don't need to use all its hyper-monetized features, and if something seems fake to you, it probably is.

On that subject, some folks have tried to fix the system by writing free textbooks available online. The most popular ones are on Openstax, which has released nearly 100 textbooks in the past few years. Unfortunately, while their mission is a great one, these proto-books aren't ready to replace polished, published books. The most rigorous Openstax book, titled "University Physics", is pitched at a much lower level than the calculus-based books listed above. Each chapter has

[3] This is what the back covers of these books mean when they say they use the latest educational innovations. In reality, it just means you type the answers to plug-and-chug problems into their system, rather than writing them down on paper. The difference is that the automated system will sometimes mark you wrong for typing $1/\sqrt{2}$ instead of $\sqrt{2}/2$, or 5.0 instead of 5.00. The actual purpose of the system to ensure that even once you have the textbook, you can be charged *again* for the homework. It's like loot boxes and DLC, but for physics.

[4] If even a used copy is too expensive, you can consider buying "international" editions of textbooks, which are sometimes marketed by publishers as "global", "Indian", or "South Asian" versions. (For example, one of the international version of Halliday, Resnick, and Walker's *Fundamentals of Physics* is called *Principles of Physics*.) These books are printed on thin paper with a flimsy softcover binding, and cost about 80% less. Usually they have comparable content, but various things like the table of contents or the index are made worse on purpose, so that people have a reason to buy the full-price version. I used to try saving money in college by buying Indian editions, but when I got Griffiths' electromagnetism textbook, the whole chapter on magnetism was missing. These textbooks are absolutely good enough to learn from, but if you have a choice you should probably get the original version.

about half as much content, and almost zero nontrivial problems. Derivations often lack consistent notation or the cleanest possible approach, and problems are often formulated vaguely or incorrectly. This isn't surprising, since the book was quickly cobbled together by dozens of busy authors.

There are also many supplemental books made for AP exam preparation, such as Schaum's outlines, and the Princeton Review, Barron's, and 5 Steps to a 5 series. I generally don't recommend them. They tend to have much higher average review ratings than real textbooks, but that's because the reviews are left by students who want to cram to pass, not learn. They are designed to get you through the simplest questions with the least possible mental effort, and as such, don't really explain how or why anything works. Not only does this suck all the joy out of learning, it'll leave you unable to answer any question deeper than a one-step plug-and-chug. They may be okay for a very quick first exposure, but you'll want to upgrade to something better quite soon.

How can I tell if I understand algebra-based introductory physics?

One decent benchmark is to try an AP Physics 1 practice exam. If you can't quickly and comfortably score a 5, you should back up and review before trying competitions. If you've already learned algebra-based electromagnetism and thermodynamics, you can also try an AP Physics 2 exam. (If you've mastered algebra-based mechanics but haven't started algebra-based electromagnetism, I would recommend instead learning calculus next, since you can't actually do much in electromagnetism and thermodynamics without calculus.)

Competition Preparation

How long will it take to qualify for USAPhO/qualify for camp/win an IPhO gold medal?

This varies depending on the person and their motivation, but here's my timeline.

- 9^{th} grade: I took a standard pre-calculus course in school and didn't know or learn any physics.
- 9^{th} grade summer: I don't recall learning anything. I grinded a lot on RuneScape, with occasional breaks to practice for math competitions. (This didn't help for physics competitions at all, besides making me a bit faster at algebra. As I mentioned on the first page, physics is different from math; it requires its own set of skills.)
- 10^{th} grade: I took algebra-based introductory physics in school, along with AP Calculus, with great teachers in both. I didn't prep for competitions, but I asked a lot of questions in class, thought carefully about the intuition behind the equations, and occasionally skimmed the mediocre *Holt Physics* book given. I just barely qualified for the USAPhO, and scored almost zero on it. But I found that experience very motivating, since it showed me that physics was full of cool problems, which took a lot more than just plugging numbers into a formula sheet.
- 10^{th} grade spring/summer: I self-studied calculus-based physics by reading the absolutely terrible Barron's AP Physics C prep book and randomly googling whenever I got confused. This took roughly 150 hours of work. Some of this was done while avoiding MOP homework.
- 11^{th} grade: I read the awesome Halliday, Resnick, and Krane textbook, thoroughly understanding about one chapter per week, and mixing in past $F = ma$ exams in January and past USAPhOs in the spring. I didn't use any other textbooks, or attend any prep courses or camps, and my school had no dedicated physics club. I just self-studied roughly 10 hours a week, for

about 250 hours in total. (It wasn't hard to find the time, since I took a minimal courseload, with a single AP class.) That year I qualified for camp, worked through ten past IPhOs as recommended by the camp coaches, and got an IPhO gold medal.

The point is that you don't need a decade of study or a ton of prep programs to succeed. And this isn't just my experience. When students on our IPhO team describe their journey, they usually say something very similar. After learning introductory physics, usually in high school, they prepare for physics competitions for a year, or two if they have lots of other things going on. Most camp qualifiers don't take any prep courses at all, but those that do only take one. All of them think about physics regularly, but none of them thought of their training as a source of suffering. Training is tough but fun, because physics is fun, and the best sources are no secret.[5]

Do you have to have Math Olympiad background to do well in the Physics Olympiad?

No. Having done both, there's very little overlap in the skills you need. The ideas that come up in combinatorics and number theory problems are almost never useful in physics. As for geometry, I haven't ever seen an USAPhO or IPhO question that required you to know more than the most basic properties of conic sections. Doing algebra problems might make you faster at simplifying complicated expressions, but those are rare in physics competitions too. Indeed, most of the members of the U.S. Physics Team have never even taken the USAMO, and the vast majority have not spent any time preparing for it. To do well at physics, you study physics, not triangle centers.

There are two reasons people might think the Olympiads are related. First, as I mentioned above, Americans only start learning physics in school ten years after starting math, so people who like physics competitions will probably have tried math competitions first. Second, in both cases a student succeeds by teaching themselves a well-defined body of knowledge by struggling through hard problems under time pressure, so developing the grit to do that for math can make it easier to do the same for physics. But math competitions are absolutely not a prerequisite: you can jump into physics even if you've never done a math competition.

Is prep program X, book Y, or course Z enough for USAPhO?

Any decent calculus-based physics course, book, or prep program is "enough", in the sense that they'll all cover everything you need. But it's up to you to turn that coverage into understanding!

What makes a competition prep program effective?

The main thing that makes a prep program effective is the student: if they aren't interested and engaged, then any program will be useless. This is obvious if you just look at the numbers. Suppose an unmotivated student is dragged to a 1.5 hour class every week for eight weeks, then grudgingly spends an hour a week on the homework. That only adds up to 20 low-quality hours of learning. If practice stops entirely once the class ends, the knowledge will be quickly forgotten. As such, there are a lot of people dragged to prep programs year after year, who never get very far. These

[5] Even bad sources can work. Recently, our IPhO teams have had students who studied with only 70 year old, $10 Dover books, or were homeschooled with no physics teacher or tutor, or who used only the rather poor OpenStax physics book, or who used nothing but Wikipedia! I don't mention this to encourage you to do the same – they would all have had an easier time if they had used better books from the start. But new students often have the impression that they're doomed unless they use twenty books or the most expensive prep programs. In reality, everybody's journey is different. The only common factor is thinking deeply about physics, and enjoying it.

programs are very popular in certain areas of the US, but in many cases seem to be a waste of time and money. Worse, when people are *forced* to do physics, they often end up hating it, which is exactly the opposite of the original purpose of the Olympiad.

Compare this to what I listed above: 400 hours accumulated over a single year. Objectively, that isn't a lot of time; people could easily spend longer than that on a single high-school course if it's loaded with busywork. But these hours were focused ones, and they were spaced out regularly. I didn't need to cram, because I'd been immersed in physics the whole time.

Unfortunately, parents often don't seem to get the message. I sometimes see them spend more energy dragging their kid through prep classes and books than their kids spend actually thinking about physics. Sometimes they even solve the problems for their kids! Parental involvement is like salt. A pinch can enhance a dish, but too much overwhelms the taste, and adding more makes it inedible. If a kid is fundamentally uninterested in an extracurricular, they should simply be allowed to do something else. There are plenty of things to do in this world besides physics.

Students often feel obligated to attend prep programs because of their effective advertising. For example, the PhysicsWOOT program run by Art of Problem Solving regularly boasts how many US Physics Team members are in their course, omitting the fact that this is mostly because the team members from the previous year get automatically enrolled for free. And prep programs for the $F = ma$ exam often claim they can "teach to the test", giving a shortcut to success. This is a myth. The $F = ma$ exam requires a broad understanding of mechanics. It's certainly possible to characterize the solutions to individual problems as "tricks", but if you don't have a foundation, there will be an overwhelmingly large number of tricks to memorize, and they'll be ten times as hard to remember because you won't know where they come from. Prep programs that rely on teaching tricks don't actually work, while those that take the time to build a solid foundation are just the same as any decent course or book. There's no proprietary secret to learning physics. You just have to think.

If it's that simple, why doesn't everybody ace the USAPhO?

Most people asking about the Olympiad have never solved a physics problem and don't even enjoy learning physics; they're just daydreaming about awards and college admissions. From my experience, out of every 100 people who ask, 75 immediately leave once they learn you need to study a good introductory physics book, like Halliday, Resnick, and Krane. Of the 25 that say they'll do that, only 10 even open the book, only 5 make it past the first few chapters, and only 1 actually deeply understands the whole thing. Really studying physics takes time and consistent effort, which filters out people who aren't interested in the subject. So at least in America, if you've thoroughly studied a good book, you're competing against less than a hundred other people. While the amount of people who *talk about* preparing for the USAPhO online has dramatically increased over the past ten years, the number of people actually seriously preparing has stayed almost the same.

I can't solve problems involving pulleys. Is there a dedicated book about pulleys?

There's no such thing. Beginners tend to classify physics problems by their superficial features, so that they'll often say, e.g. that they "can" do inclined plane problems but "can't" do pulley problems, and think the solution is to drill tons of near-identical pulley problems. But once you understand physics more deeply, you'll see that both of those classes of problems are governed by the same basic principles, i.e. Newton's laws, plus energy and momentum conservation. In general, if you find a problem unusually challenging, you should drill down and figure out what you're missing about the underlying principles, then review it in any decent textbook. In particular, you don't actually need more than one textbook for introductory mechanics.

If I know X, can I read book Z or should I read book Y first?

It depends on the context, but the answer that always works is to just try it and see. If you have a lot of trouble with the easiest exercises in a given book, then you should use an easier book. If you find the easier exercises easy, then you should focus on the harder exercises. And if you feel you're not learning anything new from even the hardest exercises, then you should use a harder book.

Do I really have to learn X if I want to win competitions?

For almost any value of X, the answer is "probably not", but if you ask this kind of question constantly, you won't do well anyway. Stop and find a different extracurricular, one where you're excited to do more rather than bargaining to do less.

Jeez, okay, but can I qualify for USAPhO without knowing calculus?

Every problem on the $F = ma$ exam can technically be solved without calculus, but most students who pass the exam know calculus-based physics. The reason is that it's hard to derive even the simplest physics equations without using calculus. And if you don't know how the equations are derived, you might only see them as a disconnected pile of results instead of an interconnected web of ideas. This penalizes you on the $F = ma$ exam, where many questions require the test taker to think very carefully about which equations apply and why. It's certainly not impossible to pass without calculus, but you're going to have to put in the time to build a solid conceptual understanding either way – and it might end up up taking *longer* if you try to do it without calculus.

In fact, this is the reason I'm somewhat against the entire idea of algebra-based physics courses. Calculus was literally invented by Newton to make physics possible; without it, you can't really derive anything. Conceptual courses without derivations can be good if they focus on their strengths: experimental demonstrations, real-world applications, hands-on projects, and inspiring exposition. (The first few Feynman lectures perfectly fit this mold.) But the typical algebra-based physics course just tries to hit all the topics a calculus-based course does, which results in students mindlessly plugging numbers into a long sheet of formulas they don't understand.

Anyway, if you're the kind of student interested in physics competitions, you would almost certainly enjoy learning calculus anyway, so you should go ahead and do so!

And what about those weird things I learned in middle school?

The standard American public school physics curriculum has a lot of things that don't really make sense. For example, we are told to remember that there are exactly 3 kinds of lever, 4 ways to write the equation of a line, 5 states of matter, 6 kinds of simple machine, and 7 steps in the official Scientific Method. I was told to round numbers to the closest digit, unless it was a 5, in which case one should round to an even digit, unless the number was negative, in which case one should round to an odd digit. In some schools, students must remember that the pound is really a unit of mass; the unit of weight is called the pound-force. In other schools, they must remember that the pound is really a unit of weight; the unit of mass is called the pound-mass. In some schools, they do multiplication and division from left to right, so that $1/2 \times 3 = 3/2$. But in other schools, they do multiplication before division, so that $1/2 \times 3 = 1/6$, and in others, division comes first.

When I was a kid, I thought this minutia was incredibly boring. It turned me off science, which seemed to boil down to the drawing of arbitrary distinctions and the memorization of arbitrary rules.[6] Thankfully, none of this trivia matters for the Olympiad, or physics in general. It's cargo cult learning, which vaguely looks like science, but in reality just keeps you busy.

But if it's really that bad, why are millions of kids subjected to it every year? And why do hundreds of thousands of teachers repeat it endlessly, exactly as they themselves were taught? Well, the underlying problem for the teacher is that solving real, interesting problems takes a fair amount of dedication and background on the part of the student. Covering minutia is a convenient alternative, because most students can be trained to do it, and an infinite number of quiz problems on it can be easily generated and graded. That's why, when the physics education researcher Edward Redish once asked his students what the most important equation in mechanics was, the most common response was $d = at^2/2$. These days, teachers can use programs to automatically generate hundreds of uniform acceleration problems, so that their classes can stay busy for decades.

In math-heavy subjects, such as physics, there often isn't enough genuine minutia to fill a whole course. So curriculum designers compensate by making up *fake* minutia that no professional actually uses, such as the ten different mechanical advantage formulas, or the amazingly complex rules for rounding. Often, the rules you're supposed to memorize don't even agree from school to school, and the reason is that they truly don't matter. No puzzle in physics has ever hinged on whether the One True Order of Operations was PEMDAS or PEDMAS, even though people never seem to tire of debating it on social media. If you're like I was as a kid, you'll want to ignore this noise altogether, but unfortunately grades[7] are still quite important at this stage in your life. My advice is to grit your teeth, learn it just well enough to maintain decent grades, and immediately forget it. Treat schoolwork as a day job and save your energy for deeper things.

Of course, some of the arbitrary-looking stuff you learn in school actually does turn out to be important. For example, you'll probably spend a lot of time manipulating matrices, in what seems to just be a complicated way to rewrite basic algebra. Most school teachers can't tell you why this is worthwhile, but matrices turn out to be extremely important in more advanced physics. So how can you tell what you need to know? In general, you can avoid this problem by sticking to good books. They'll contain exactly what actually matters.

[6] And learning these questionable rules is the good part; most of the time you just work on cutesy crafts. If you didn't go to an average American public school, examples include drawing hand turkeys, decorating cupcakes, sculpting mitochondria, and making collages. In a typical week, I would make a burger-shaped book report, a Lego model of Lithium, and a mosaic of Manitoba. I'd also have to bug my Chinese-educated parents to buy construction paper, *not* regular paper, leaving them wondering why I needed scissors, glue, posterboard, and 5 colors of paper just to learn long division. Indeed, most non-Americans are surprised by our emphasis of crafts over actual information, which ultimately stems from certain modern educational philosophies. These philosophies say that it's a sin for a teacher to simply *tell* students what's true; they should construct it from themselves. In practice, what this meant is that we'd receive about two sentences of information, then get assigned some random topic, like quokkas or quasars. Then we would spend hours copy-pasting from Wikipedia, with the teacher occasionally swinging by to remind us to "use critical thinking", which was kind of hard when nobody knew what the hell was going on.

[7] Grades can be a decent indicator of learning if you have good teachers. But if you have bad teachers, they just indicate obedience: whether you were able to parrot back dubious information, quickly and reliably, with a smile. And we all know that the most expensive private schools give out the most A's. So given the well-known problems of grades, one might think it would be better to measure students in a way that has been carefully developed, refined, and standardized by a competent outside party, such as an exam of some sort... but in the United States, such exams are drastically watered down and deeply out of fashion. That's why competitions are so important. They are even more controversial among educators than standardized tests, since many educators view any kind of competition as immoral, but the truth is that the competitive aspect is irrelevant. The real point of competitions is that they're one of the few places left you can put your skills to work on nontrivial problems, to see if you truly understand something. And they're *definitely* the only place you can do that with no budget or outside help.

And do I need to learn advanced topics, like linear algebra or quantum mechanics?

Students often think this is necessary for three reasons: (1) Olympiad questions are often related to advanced topics, (2) successful Olympiad participants often know a lot of advanced physics, (3) students preparing for math competitions like the AMC or AIME often read big stacks of Art of Problem Solving books. All of these are misleading. The Olympiad syllabus is centered around introductory physics, and questions are carefully designed to be solvable without any advanced knowledge. (In fact, trying to use more advanced tools often results in a slower solution!) Successful participants often know a lot of physics not because it's particularly helpful for competitions, but simply because they like learning things. And a single introductory physics textbook is a lot denser than an Art of Problem Solving book, because it has to build a whole subject from the ground up. It's great to explore more advanced topics, but at the same time, you shouldn't feel obligated to.

How should I prepare for the $F = ma$ exam?

The main ingredient for success is a solid understanding of mechanics, which you can pick up from any calculus-based physics textbook. I particularly recommend the first 17 chapters of Halliday, Resnick, and Krane (5th edition), since it has plenty of tricky multiple choice questions. Once you're done, you should also prepare for the quirks of the $F = ma$ exam, but don't get the priority flipped: exam preparation should take a couple dozen hours at most, while learning the foundations takes hundreds of hours. And the foundations come first.

Anyway, the $F = ma$ exam throws tricky multiple choice questions at you under extreme time pressure, and the best way to prepare for that is to train on similar problems under timed conditions. There are over twenty past $F = ma$ exams publicly available, which gradually increase in difficulty over time. If you want an even gentler start, you can try the ten $F = ma$ exams from before 2007, though many of their questions are quite routine.

After a practice exam, you should immediately check against the answer key, and understand how to solve any question you missed. (Earlier $F = ma$ exams don't come with detailed solutions. For 2011 through 2019, you can use the solutions in the book by Kisacanin and Zhang, which are distributed for free on the AAPT website. From 2018 onward, there are also detailed official solutions.) Another excellent resource is Morin's *Problems and Solutions in Introductory Mechanics*, which contains a lot of multiple choice questions, with explanations, at about the right level.

If you run out of problems, you could also try past PhysicsBowl questions, the CAP prize exam, the first round of the British Physics Olympiad, or the Hong Kong Physics Olympiad. However, all these competitions are significantly more straightforward, and some contain non-mechanics questions. The existing $F = ma$ exams should be more than enough if you use them thoughtfully.

If you prefer the structure of classroom-style instruction and have some spare cash, you could consider the courses by Art of Problem Solving, AwesomeMath, or Tang Academy. However, you should keep in mind that none of these courses are a replacement for learning basic mechanics – you must already have a solid mechanics background to get anything out of them.

I lost many points on the $F = ma$ exam due to silly mistakes. How do I avoid them?

If you think you have this problem, it's probably not because you have some issue with doing basic algebra. After all, if you're taking the $F = ma$ exam at all, then you passed introductory algebra, which means you can do algebra with fairly good accuracy. The higher rate of "mistakes" on the physics exam is often the result of a lack of understanding, not random error. It's like a chess player saying they lost a match just because they momentarily thought their bishop could move like a knight, or a basketball player missing a shot because they were confused whether they had to throw it with their hands or kick it with their feet. These kinds of mistakes are unimaginable to experienced players, even when distracted or tired, and arise from a lack of familiarity with the rules of the game. Here are some concrete tips:

- Make sure you have a strong conceptual understanding of mechanics. Errors in manipulating basic equations will often immediately lead to absurd results. For example, if you manipulate $F = ma$ into $a = m/F$ you'll conclude that an isolated object has infinite acceleration, which makes no sense. More generally, you can often simplify a problem by taking limiting cases, i.e. by considering when some of its parameters go to zero, infinity, or become equal to each other. Check that your answers make sense in as many limiting cases as possible. If possible, visualize your answer happening with objects in the real world, and see if it fits your intuition.

- Check the *ingredients* of a calculation. If you make a mistake in a calculation, and you check it by just reading it again and running through all the steps in your head, in the same order, you'll probably skip right over the mistake. Instead, try to check in a way that separates the problem's essential parts. For example, I like to do a "starting point" check to see if every ingredient going into the derivation is right. Then, for the derivation itself, I do a "no number" check where I ignore all the numbers, and just make sure that the variables are showing up correctly, i.e. that something that should be in a numerator doesn't end up in a denominator. Finally I do a "number only" check where I only track things like factors of 2. In each check I have to pay attention to only a few things at once, which makes it easier to catch errors.

- Organize your work as linearly as possible, keeping work from a single problem together. If you realize something you wrote is wrong, make sure you clearly mark that in some way.

- Understand the reason a problem can be tricky. If you think a problem can be solved in five seconds by directly applying a single standard formula, then it's worth thinking for a whole minute about whether that formula actually applies.

Any advice for the USAPhO exam?

As mentioned above, the best way to prepare for the USAPhO is to spend about a year thoroughly learning calculus-based introductory physics, from a resource like Halliday, Resnick, and Krane, while mixing in previous exam problems for practice. You can then dive deeper into specific subfields using the resources listed in my second advice file, which generally shouldn't be necessary, but will make USAPhO problems in that subfield a lot easier to approach. Here are some further tips:

- Generally, problems gradually increase in difficulty in time, so it's best to try USAPhOs in roughly chronological order, starting in 2007. If you want an even gentler start, the handout syllabus contains links to pre-2007 USAPhOs, and also to "quarterfinal" exams, which used to go between the USAPhO and $F = ma$ exam.

- It's good to practice under realistic conditions. When doing a USAPhO problem, work on it uninterrupted for at least the full time limit (i.e. at least 30 minutes for recent USAPhO problems), and write a solution as you go, boxing a definite final answer. Problems are scarce, so you should never waste one by turning to the official solution before giving it a good try.

- People often ask how the USAPhO is scored. Compared to other Olympiads, such as the USAMO and USACO, the USAPhO has generous partial credit, as you can see from a past rubric here. To get the most of it, you should write your solution clearly. The logic should flow linearly down the page, and your handwriting should be legible, especially for your final answers. You don't have to write full sentences, and you can get full credit without writing a single English word, but it's good to add short explanatory phrases (such as "by conservation of energy" or "by solving the above two equations"). If you make a mistake on one part that propagates to a later part, you generally won't get double penalized, unless your mistake changes the problem qualitatively (e.g. by violating dimensional analysis or limiting cases).

- Anything covered in a standard introductory physics textbook can be used without derivation or justification. (More advanced tools, such as Lagrangian mechanics, can also be freely used, but usually won't help. For instance, 2019 B3 can in principle be solved with Lagrangians, but in practice it is much easier to just think carefully about the definition of acceleration.) On the other hand, 2022 B2 centers around *deriving* the Lorentz invariance of electric charge, $Q' = Q$, using a thought experiment involving time dilation; in that case you can't get full credit by ignoring its subparts and just writing $Q' = Q$. So the general rule is that you can use any result, unless the problem is explicitly about deriving that result.

- In high school, you might have been made to follow silly rules to avoid losing points. For example, you might have always had to draw a free body diagram, even in cases where it wasn't necessary or didn't help. Or you might have had to write equations in a particular format, such as $x_f = x_i + v_0(t_f - t_i) + a(t_f - t_i)^2/2$ in a case where $d = at^2/2$ would have sufficed. These rules are crutches, enforced by teachers because they make grading easier, and help average students reliably solve plug-and-chug problems. They don't apply on the USAPhO.

- As for simplifying your answers, use common sense. If the answer is $\sin\theta$, and you write $\sqrt{(1-\cos^2(2\theta))/(4\cot^2\theta\sin^2\theta)}$, you're going to lose a few points. If the answer is $2\sqrt{2}$ and you write $\sqrt{8}$, it's fine. There are no secret weird rules you need to know about. Just simplify so that the structure of your answer is clear. That will also help you tell if your answer is right.

- You should also reserve a few entire USAPhO exams to take in one sitting, to practice time management during a full exam. I recommend reading all of the problems at the start of the exam, and beginning with whichever looks most approachable. It's important to avoid spending too long on any one problem, as some can be much harder than others. If you get stuck, try moving to a different question, or going back to check your work on an earlier question.

- The USAPhO always has at least one completely new idea every year (e.g. liquid-gas phase transitions in 2015, op amps in 2016, entropy conservation in 2017, diodes in 2018, rotation with a changing pivot in 2019, nonideal gases in 2020, convection in 2021, and bending moments in 2022). You shouldn't be discouraged if they look unfamiliar. These questions are designed to test your ability to learn and use new concepts, as would happen on the IPhO, and they always contain enough information to solve without special knowledge. Be ready to adapt!

- According to past statistics, the median student gets about 20% of the points, and almost no students get above 75%. So in the modern USAPhO with its 6 equally weighted questions, a *very* rough guide is that the honorable mention cutoff corresponds to 0.5-1 questions, bronze to 1-2, silver to 2-3, gold to 3-4, and slightly more than that qualfies for camp. (Of course, the cutoffs vary from year to year depending on the difficulty, and you can also accumulate points through partial credit.) If you passed the $F = ma$ exam and know calculus, it's not too hard to get an honorable mention by making an honest effort on the mechanics problems, and if you want to go to camp, you have to solve most of the exam, but not the whole thing.

- Don't give up if the first problem seems hard, or get complacent if the last problem seems easy, or obsess over exactly where the cutoffs are. Difficulty varies from year to year. Almost everybody comes in with a similar introductory physics background, so if you feel a test is unusually hard or easy, then others will too. During the exam, you should spend absolutely zero time worrying about how others are doing, and just concentrate on doing the best you can.

Sir, what are your tips to crack JEE?

Since India is the world's largest English-speaking country, I get a lot of questions along these lines, but I really can't help, because Indian exams differ from American ones in many ways. First, for historical reasons, India's physics curriculum is a lot closer to that of the former Soviet Union. That means there's a lot more emphasis on elementary mechanics, optics, circuits, and nuclear physics. Second, the JEE is *very* competitive: of the million students take it every year, many of whom spend their high school years living in coaching institutes, only about 1% are admitted to the IITs.

For this reason, anyone who spends time discussing physics on the English-language internet will constantly be told that the JEE is the hardest exam in the world. And for a long time I thought this was the case, until I saw the test itself. There are only two minutes allotted for each multiple choice question, which is far too little for any to require deep thought. Instead, the exam is made difficult by centering those questions around a vast amount of minutia that must be memorized.

For example, in magnetostatics, students are asked for the magnetic field of a polygonal wire, or the off-axis field of a solenoid. A top US student will derive these results in ten minutes, but the exam only gives two. It expects you to have them already committed to memory, so you can just mindlessly plug the numbers in. Worse, sometimes students are expected to memorize incorrect or meaningless formulas. For instance, they need to remember that the "magnetic poles" of a bar magnet are located exactly 1/16 of the way from the end – even though magnetic poles don't exist.

There are countless more examples, across all fields of physics. Students learn trivia about surface tension that isn't true. They are tested on the fine details of reading Vernier calipers, though the vast majority will never use one. And the questions are often missing information or poorly posed, putting thoughtful students at a disadvantage. The situation doesn't even improve when you look at the hardest questions on the JEE Advanced. Sometimes, they are famous, beautiful puzzles that can't be solved properly in two minutes; here the difficulty is fake, as the most common method of "solution" must be seeing it before, and memorizing the answer. Other times, they are incorrectly formulated, with no correct answers, because the exam writers themselves got confused.

As a result of this poor exam design, Indian students often tell me they plan to skip learning any "theory" to save time for "problem solving". When I first heard this, I was very confused. How can you have one without the other? Any decent textbook should explain the theory and then show example problems. But apparently, in South Asia it's common to study problem solving *without* theory, in the sense that you just memorize a lot of formulas and procedures without asking why they work, or even if they make sense. I understand that not everyone has the time or inclination to really understand the subject. Blind memorization probably *is* the most efficient way for the average student to scrape by. But when it becomes the default method, competitive exams degrade from a useful tool to motivate and measure learning, into an enormous waste of time.

That's what Indian Olympiad team members have told me. In the Olympiad system, students are expected to remember almost nothing, but they need to understand how physics fits together. That enables them to solve completely new problems after some deep thought. By contrast, the JEE system rewards broad knowledge, shallow pattern recognition, and raw speed. I suspect the dominance of this system is the reason that India, with its vast numbers of highly talented students, performs worse at Olympiads than much smaller countries like Taiwan and Singapore.

Other Questions

How can I meet other students?

Currently, the most active English-language community for Olympiad physics is this Discord server. Chatting is fun, but don't forget that talking about doing physics doesn't replace actually doing it!

How can I preview PDFs of textbooks and papers before purchasing them legitimately?

For books, try Anna's Archive or Library Genesis. For papers, try SciHub.

What's the best way to spend my time learning?

Here are some principles that almost everyone, from teachers to researchers to bloggers, agrees on.

- Don't passively consume content. When you read about a new physical idea, turn it over in your head. Ask yourself where you've seen the idea at work in the real world. Look at its logical development – what assumptions do you need to get from one equation to another? Get a feel for how each equation behaves as the variables vary. Take limiting cases of them, relating them to ideas you already know, or try to go beyond, seeing where they might fail. Try to reconstruct the idea, in a way that makes it intuitive. Do practice problems, or make your own. Many students don't do any of these things, but claim they "understand the concepts" because it "all makes sense". They are experiencing the "illusion of explanatory depth", mistaking vague familiarity for true understanding. If you're actually thinking about the material, you *should* occasionally get confused; learning comes from noticing and resolving such confusions.

- Avoid skipping around. Sometimes, students skip straight to the exercises, figuring that they can "learn by doing." Then, when they get stuck, they haphazardly skim the text for equations which seem to contain the right letters. (This is also a common problem for study groups working on problem sets.) This procedure tends to make one-minute exercises take an hour, and doesn't work for nontrivial exercises at all. When you're starting out, it's most efficient to spend a comparable amount of time learning theory (which includes both reading and thinking) and solving concrete problems afterward. And theory should be learned linearly, in the same order as the book's chapters, to avoid unnecessary confusion and backtracking.

- Take time to chew and digest the ideas – at least a few hours per textbook chapter. Everybody has their favorite way of doing this. Old people often insist that the one *true* way to learn, as intended by millions of years of evolution, is to write full English sentences in cursive with a fountain pen in a leather-bound notebook. But I type my notes in bulleted lists and others use web-like structures such as mind maps, or even no notes at all. I have a friend who just walks in circles mumbling to himself, and it works for him. I take occasional notes in the margins of my books, while others keep them pristine. As long as you're actually thinking about what you're reading, none of these details matter. Use whichever you like best, and it'll work as long as it keeps you engaged with the ideas.

- On a related note, it doesn't matter much whether you primarily learn theory from books or lectures. The average book is probably clearer than the average lecture, since books often emerge from refinements of lecture notes. But lectures can be more engaging, because the instructor presents live, in the flesh, in a room full of other students paying attention. Books can drown students in too much detail, but lectures can keep students from thinking if they're too busy taking notes. Sometimes students zone out in lecture and don't remember anything at all, but students also do the same with books, mindlessly rereading while highlighting every word. Similarly, compared to live lectures, recorded lectures have pros and cons: you can rewind, pause, or speed them up, but in the absence of a definite time slot you might never get around to watching them at all. The point is that, even though there's little empirical evidence that people have different "learning styles", people do vary in what gets them to effectively focus. There is no one best option, and all of them can work, so choose whichever you like most.

- The best way to remember something long-term is spaced repetition: apply the idea the moment you learn it, then reencounter and reuse it regularly. Good physics books and courses will automatically make you do this, as long as you work steadily and linearly through them, solving a good number of problems. (There are many online advocates of spaced repetition via flashcards. The idea is to break a book into thousands of tiny chunks, put each chunk on a flashcard, and randomly show yourself the flashcards using programs like Anki or Memrise. For example, one flashcard might ask you "acceleration of a block down an inclined plane", and the other side of the flashcard would say "$g \sin\theta$." The issue is that this is only good for subjects that are broad, shallow, and repetitive, like learning vocabulary words in a foreign language, or preparing for medical school exams. In Olympiad physics there just isn't that much to memorize, and solving new problems requires *actually thinking*, instead of kneejerk reacting by rewriting the solutions to trivial problems. On a similar note, you should avoid silly mnemonics for basic equations. Mnemonics are useful in other fields because they can give some artificial meaning to something totally random, and people are best at remembering meaningful stories. But physics equations aren't random: they actually make sense, and if you understand why they make sense, you'll easily remember them.)

- Do practice problems just above your current level. Trivial exercises alone won't make you ready for harder ones, and if you do too many you'll probably get bored, zone out, and start making dumb mistakes, making the practice totally useless. On the other hand, if you skip to very hard problems, you might spend long stretches of time making zero progress, or trick yourself into thinking you see the answer without understanding the subtleties at play. Aim for a difficulty level where you can work out most, but not all, problems completely by yourself. Your practice should feel effortful, deliberate, and possibly a little uncomfortable.

- Don't fool yourself by relying on solutions. A solution is useless if you haven't already given a problem a good try first. Many students end up exclusively reading solutions without being able to work out anything for themselves, but feeling confident because the solutions "make sense". ("I got it wrong at first, but now that I've read the solution it looks easy!") This is as effective as trying to learn an instrument or sport by only watching others play it. When the inevitable happens, students often say they "froze up", "blanked", or "don't test well". But the truth is that they didn't forget anything – they never developed the skills in the first place.

- When you finish doing a set of practice problems, reflect on how they went, and if you weren't able to do some of them, figure out the crucial steps you were missing. This is especially important if you're self-studying, as there won't be many other ways to get timely, objective feedback, which is absolutely necessary for learning.
- But don't get feedback *too* fast. For example, it's tempting to flip to the solution manual the moment you get an idea, to see if you're right. But generating ideas is only part of the problem solving process: you also need to implement the ideas, check whether they're sound, search for alternative ideas, and (most subtly of all) evaluate when you can stop searching. These skills are all crucial for competitions, research, and life in general. You should only check a solution once you've gotten totally stuck, or carefully thought and committed to a final answer.
- Make sure your studying is healthy. Long cram sessions aren't effective. Take regular breaks instead of sitting motionless for hours. Sleep enough to feel rested, drink water, eat food, and generally obey common sense. Studying when your brain or body is tired is only useful for mindless tasks like cramming things into short-term memory, the opposite of what you need.

How should I self-study from Halliday, Resnick, and Krane for the USAPhO?

First off, I want to reiterate that it's a bad idea to start with this book if you don't know any introductory physics, or are shaky with calculus. If you don't have that background, you won't even know if you actually *like* physics, so why bother preparing for a tough physics competition?

Anyway, Halliday, Resnick, and Krane has 52 chapters (though the last 6 are on advanced topics), and each chapter comes with multiple choice questions, conceptual questions, exercises, and problems. A good pace would be about one chapter per week, or three chapters per two weeks.

If you're self-studying, it's essential to continuously test your knowledge, to avoid gaps in understanding. While reading a chapter, you should spend at least as long thinking about its contents as you do physically reading the words. Afterward, spend at least a moment thinking about every conceptual question, as many of them help you connect the theory to the real world, and some are surprisingly deep. I also recommend doing all of the multiple choice questions, since they are excellent preparation for the $F = ma$ exam. But it's not worth doing all of the exercises, since many are just plugging numbers into standard formulas. Skim them to see if you know how to do them, and try a small sample to check.

On the other hand, I recommend reading all of the problems carefully, and doing at least half of them, depending on which strike your interest. Note that while some of the problems aren't too different from exercises, a few (such as 4.12, 5.11, 7.12, and 17.8) are much harder. You shouldn't get discouraged if you get stuck on them, but you shouldn't ignore them either, as these tougher problems illustrate key ideas that are very important on the Olympiad.

Answers to odd-numbered exercises and problems are at the end of the book. An official solution manual to all exercises and problems can be found online, but I don't recommend relying on it in detail. It's designed for instructors to quickly check answers, and as a result, its explanations are quite brief, and sometimes a bit sloppy. (When I was preparing, I didn't even know there was a solution manual!) There are no official answers to the multiple choice questions, but you can find my answers for the first 17 chapters here.

What are some important traps to avoid?

If you're at a "top" high school, the biggest trap is confusing your schooling with your education. A mild case of this looks like signing up for every AP class your school offers, spending all your nights and weekends grinding out busywork you don't really care about, and then obsessively reading rubrics to argue a grade of 97% up to 98%. A more advanced symptom is jockeying for positions within your school's many fake clubs – that is, clubs which do nothing besides elect a gigantic slate of "leadership" positions, make a shiny website listing those leaders and the "social impact" they'll have, and then do absolutely nothing for the rest of the year. In the terminal stages of this disease, you could end up paying a lawyer to found a fake nonprofit for you in junior year, just because twenty of your classmates did. People act in this undignified way because they think it'll get them ahead in our broken system, but that's really not how it works. Even admissions officers are smart enough to see through this most of the time, and even if they couldn't, it still wouldn't be worth doing, because it leaves no room for real education![8]

These "good" high schools often produce another trap: obsessive comparison. Sometimes students will convince themselves they can't succeed in physics, because while they got a 99 on a quiz, some other kid in the class got 100. Or they monitor the ages of everybody accomplishing things in their school, despairing if anybody required one fewer month of living to do something they did. This is all silly, because learning is about what *you* do, not what others do. For example, I mentioned above that when I was in 10$^{\text{th}}$ grade, I found the USAPhO completely impossible. What I didn't mention is that the same year, one of my classmates made the US Physics Team. Over the next year, we both studied hard separately, and both won IPhO gold medals. The point is that learning is not an exclusive act, and somebody knowing something doesn't stop you from knowing it too.

It's also important to remember that you're a person with flesh and blood, not just a brain on a stick. Lots of people spend thousands of hours studying in high school, and nearly zero exercising. That's a mistake: being in shape gives you more energy, and makes *everything* in life much easier. (Anecdotally, it even seems to make people better at experimental physics exams!) Don't fall into the trap of thinking that the world's divided into fit "jocks" and smart "nerds", because the happiest and healthiest people can do both. Even if you can't be bothered to get to a gym, you can make a lot of progress with bodyweight exercises. For example, when you're doing long problems you can take breaks by busting out pullups, pushups, or pistol squats.

Another common trap is overweighting the qualitative or the quantitative side. People in the first category often say things like, "I don't need to do any calculations, because I really understand the concepts!" People in the second category will say, "Who cares why that works – I got the right answer this time, didn't I?" Of course, both are misguided, because to solve nontrivial problems you'll need to be comfortable with both sides. Now, at the frontier, it's definitely true that there are leading researchers that lean one way or the other. But make no mistake: all of them knew both sides of the fundamentals extremely well. You might see pop science portray Newton and Einstein as daydreaming visionaries, but their breakthroughs were enabled by years of grinding out concrete

[8] By the way, you can also go wrong by going too far in the opposite direction. Smart students often intuitively see how fake the scramble for "leadership" resume items is, and some respond by resolving to do everything alone. But while the system is definitely broken, it was originally intended to encourage you to develop genuinely useful skills. In particular, you can develop your communication skills by working with others on physics problems, or helping them understand points in your physics class. The ability to talk with people of different backgrounds becomes more important the further you get into physics research.

calculations with their immense technical skills, as you can see from their notebooks.[9]

Overplanning is another common trap. A lot of people get caught up on finding the *optimal* books and the *optimal* practice problems, and never actually starting to do either. I often hear from students who have made totally unrealistic multi-year schedules. They plan to read all of HRK in a month, before even looking at the first chapter, and their primary concern is what they'll do once they finish every textbook in existence. This is a bizarre failure mode with a simple root cause. Often, these students know so little physics that they don't have any idea if they like it. They just have a vague feeling that they ought to have something science-related to put on their college apps. Since they lack real interest in the subject, they are repelled from actually doing it, and instead spend their time dreaming about winning competitions (or, in the case of the adult student, of defending the credit for their Nobel prize). Overplanning is a form of fantasy.[10]

Again, sports are a good analogy. Consider somebody who made their country's youth soccer team. They probably started by playing casual games with their friends, perhaps on their school's team, gradually building up their skills while having fun. As they got better, the stakes were gradually raised, until they ended up going to tournaments and doing daily deliberate practice with a coach. But it wouldn't have made sense to go looking for that coach before their first-ever soccer game! You don't *start* with planning, you start by playing the game and seeing if you enjoy it.

In both sports and physics, long-term motivation comes from small, consistent wins, not distant goals. The elite athlete gets through a 6 AM practice session by focusing hard on improving their fitness and technique. The great physics student leaves a study session excited by what they've learned about the world. You can momentarily fake this feeling by making a big planning spreadsheet, downloading twenty textbooks, or watching motivational YouTube videos, but none of these things alone will get you anywhere. To learn physics, you have to regularly do physics.

But will Olympiad physics medals help for college?

If you mean American college *admissions*, keep in mind that they're decided by admissions officers, not professors. The average Ivy League admissions officer is a recent college graduate with an English degree, who forgot the quadratic formula long ago. While online forums for "chancing" anxious high school students obsessively rank the prestige of various competitions, the truth is that most admissions officers can't remember the difference between them. It's easy to forget this if you focus exclusively on math and physics, but students in general can specialize into *hundreds* of activities, such as quizbowl, painting, dance, and countless sports and musical instruments, each of which has dozens of similarly-named competitions that vary enormously in rigor. It's too much for anyone to keep track of. So if you put your $F = ma$ exam score on your resume, they certainly won't know what counts as a high score, they probably won't know the exam is nontrivial, and they might

[9] People also like to say that Einstein failed math in school, became a patent clerk, then randomly figured out relativity in a stroke of intuitive inspiration. Every part of that inspirational story is totally wrong. Einstein taught himself calculus at age 14, aced the entrance exams for a top university, and wrote his *annus mirabilis* papers while finishing his PhD at a top graduate program. He only worked as a patent clerk for a short time between being a PhD student and a lecturer. If you want to do fundamental physics research, the best route is almost always through the normal academic system.

[10] There's a variant of this trap which has emerged recently, as a result of the increased amount of discussion online. An energetic but naive student announces "I just started book X!", and receives pointless responses like "That's nothing, book Y is so much harder." The student jumps to book Y, convinced it's the secret to success, and the process repeats a week later. After a while, the student will have read the first chapter of a dozen undergraduate and graduate textbooks, gaining a fantastic understanding of kinematics and electrostatics, but never progressing further.

not even realize that it's about physics![11] The only exceptions to this rule are the STEM-focused top schools, MIT and Caltech, which have specialized training programs for their admissions officers. So most US Physics Team members are admitted to MIT and choose to go there.[12]

At other universities, even prestigious ones, the admissions office can't reliably distinguish among the top 2% of physics students. You're in this group if you pass AP Physics C, and at that point the decision rests on the vibes a random officer gets from your last name, and your essay. By staring at that single page, that person will try to infer your personality, your passions, and your pedigree – largely by collapsing you into a stereotype. You shouldn't spend years obsessing over impressing such people. It's not worth it, and furthermore, the things that will really impress them are out of your control. These are folks who see math as nothing more than an instrument of pain, and think solely in terms of tragic stories and grand narratives. They are interested in the circumstances of your birth, the intimate details of your personal life, and whether you have a polished story of it all. Buying such polish takes a lot of money. Recently released documents show that, besides race, the best predictor of your Harvard "personality" rating is whether your parents have a top 1% income ($650,000 per year). Your score on an exam with a $10 registration fee will never thrill them in the same way. So if you only wanted to study physics for your college apps, this is your warning! It's not your One Weird Trick to getting in, and it takes quite a lot more mental effort than similarly prestigious activities.

The real point of physics competitions is to motivate students to learn things, so the more important question is whether competition experience helps for the classes in a physics major. The answer is absolutely yes. You'll be able to skip to at least sophomore physics classes. Many people struggle with those classes because they will be encountering real problems for the first time, which require more than a single step, but you'll have already seen problems that need many steps, and even some that require creative leaps. In a typical college physics course, you will solve a "problem set" every week, for a total of a few dozen problems in a semester; you'll have already done hundreds of comparable ones using the same problem solving skills. Most importantly, since you won't have to worry about surviving the problem sets, you'll have space to think deeply about the big ideas. Such thought is one of the most pleasurable and rewarding parts of being a physicist.

[11]This is what I've learned from talking to real admissions officers. But if you can't believe it, just put yourself in their shoes. Your application is sitting in a giant pile; the person before you in the pile is a trumpet player and horseback rider from a famous private school, and the person after you is a debater and nonprofit founder from an urban public school. When the officer gets to your application, they have 5 minutes to decide whether it's worth a second look from the full committee. Only about 0.1% of high school students take the $F = ma$ exam, so they probably don't even remember the last time somebody mentioned it. And even if they did, how would they know that the Physics Olympiad is much harder than the Physics Bowl, but much easier than the Physics Cup? It's easy to get obsessed with hierarchies in your own world, and forget that it's a tiny, tiny piece of the wider world.

[12]MIT is an outlier in many ways. In 2023, it was the only top US school that required SAT/ACT scores, and it remains the only one that doesn't give legacy preference. Compared to every Ivy League school, it has the least wealthy incoming students, but its outgoing students become the most wealthy a decade later. It's also very transparent, with many of its admissions officers posting their thoughts publicly. Unfortunately, MIT's relative transparency, fairness, and rigor often makes people think the process at *other* top schools is much better than it actually is. The real process used at Harvard, Yale and Princeton is explained in *The Chosen*. I don't recommend reading it, though. It'll just make you feel depressed, and in any case it's out of date – the situation has gotten worse since it was written. Without a doubt, the worst part of the Ivy League system is its air of moral judgment. Adults like to think the system is fair, so if you know your stuff but don't get in, they'll simply assume it's because you're a *bad person*, in some subtle way only an admissions officer can detect. Regardless of what the law technically allows, in practice we have a system where this extremely homogeneous group decides, with just vibes and last names, whether you have a soul. The only dignified response is to ignore them.

Do I have enough talent to make it?

In response to this difficult question, many well-intentioned adults assert that talent does not exist, or that anybody can do anything if they really try. These trite sentiments come from a good place, but they're rarely satisfying to their recipients because they're clearly not true.[13] Talent does exist. It's the reason that wealthy families can spend tens of thousands of dollars propping up or outright falsifying their children's SAT scores, to get outscored by less advantaged kids using only the $20 Blue Book. More dramatically, it's the reason that Ramanujan went from being the son of an Indian clerk, doing mathematics alone in near starvation, to the apex of mathematics in Cambridge.

The more nuanced story is this: in legitimate systems, success comes from ability, and ability comes from focused, effective practice. Dedicated practice comes from interest, and interest is mediated by a combination of talent and socioeconomic factors.

To illustrate this point, consider the extreme case of child prodigies. Prodigies exist in chess, music, math, and programming, but not in law, medicine, history, or literature, because the former allow rapid learning and feedback, starting from minimal background knowledge. Children naturally learn quickly, and a child knows immediately whether they've won or lost at chess, and when they've made a clever move. Talent determines how often these exciting wins happen, and if there are enough, a child can take a liking to chess, and begin a phase of rapid improvement.

Of course, socioeconomic factors play a role. Chess prodigies need someone to introduce them to the game in the first place. They need stable homes and supportive parents, so that they have space to focus on learning. They benefit from chess-playing adults they can look up to, a community to help them learn faster, and a system of competitions to help them set goals and measure their progress. That's of course why chess prodigies appear in the West, Go prodigies appear in Asia, and neither appear in bad times.

What does this have to do with physics? When I was a kid, I had a naive view of physics based on talent. I thought every "level" of physics required some minimum bar of talent, and that people just kept climbing until they hit a wall, a level of abstraction they were simply unable to grasp. After all, that's how adults talked about it. They'd say things like, "math stopped making sense for me at trigonometry", or "I couldn't make it past differential equations." So when things got hard, such as when I started quantum field theory, I had a sinking feeling that I was "hitting the wall."

But in reality, the cognitive load of learning stays relatively constant. With modern resources, the difficulty of learning quantum mechanics is about the same as learning introductory physics, *provided you have equal mastery of the prerequisites.* The reason people hit walls is largely not because the material gets inherently harder, but because they finally fall through the massive holes in their foundations. For example, algorithmically, differentiating functions is not more complex than doing long division: the number of things to keep track of, and new rules to apply, is comparable. But people get stuck at the former because it tends to expose all the misunderstandings they've ever had about basic things, like simplifying fractions. That's the problem; it can't be the raw complexity of manipulating the symbols, because all of us can follow a much larger set of rules for manipulating a much larger set of symbols, whenever we assemble letters into words and sentences.

While I brought up child prodigies to illustrate a point, they shouldn't worry you in physics, even though they certainly exist. Sometimes people give up because they know people younger than

[13] Frankly, they can even come off as insulting. Sometimes I see people on the internet confiding that they've always been unable to do basic arithmetic or algebra, despite extensive effort. They always get a hundred replies along the lines of "I never had trouble and I'm just average – have you considered actually trying?", or worse, "I'm just like you and I had trouble too, I couldn't pay attention because it was all just *too easy*!" This kind of humble-bragging never helps anybody.

them who are "ahead". This makes as little sense as worrying about all the people older than them who know more. How are you ever going to catch up to the people who are already in graduate school? The question doesn't make sense, because success doesn't come from "catching up" to people. Success in physics requires accumulating a body of knowledge, which takes on the order of one year for high school physics competitions, and ten for physics research. People who get to that point earlier in life just get a few extra years to use it; they don't stop you from doing the same.

Indeed, you shouldn't ever worry if you, or others, are ahead or behind of the "usual" track, which is an arbitrary designation that changes all the time. The all-time top voted post on Reddit's AskPhysics is a warning to avoid learning anything faster than your high school teaches. But how do you know if your school is going at the "right" speed? For example, if you're from the United States, you probably took Algebra I (with problems like "solve $2x + 3 = 5$", and "plot $y = mx + b$") at or before the age of 13. Was this correct? In many European and Asian countries, this sort of material is covered well before age 13, so you're behind. But the California Math Framework says that, for the sake of equity, all students should learn it for the first time together in 9^{th} grade (age 14), so you've unfairly skipped ahead. That is, if you trust politicians to tell you how to learn math.

The truth is that there's no one right age to learn algebra, or calculus, or quantum mechanics. When educators argue about it, they're thinking about how it will impact averages, such as the achievement gap or the PISA ranking. They're not worrying for a moment about how it affects bright students, who contribute negligibly to statistics. If you're such a student, the best response is to secede. Ignore this debate, sit at the back of the class, and teach yourself whatever you want.

When people on the internet complain about "being behind" or others "skipping ahead", they're just expressing their own insecurities. There are many paths and timelines to success. I've met child prodigies, but also tons of great researchers who never did the Olympiad, or didn't do any physics in high school, or even didn't do physics until the end of college! What you should learn next is determined by your goals, interests, and prior knowledge, not your age.

So let's say that when you first learned physics, things clicked for you. You saw the world in a different way, it felt good, and you wanted to learn more. If this rings true, I can assure you that if you keep going, it'll keep paying off. You'll continue to get "aha!" moments. You'll continue to piece together, with concentrated effort, new ways of looking at the world. Of course, the *rate* at which you do this depends on talent. But if you've made physical insights before, you will make them in the future, if your foundations are good. There is no wall; how far you go is up to you.