Advice For Introductory Physics

In this file I answer some frequently asked questions about learning physics and entering physics competitions. For general logistical questions, see the USAPhO FAQ on the official AAPT website. For advice for how to continue after finishing introductory physics, see this file.

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. This background is typically provided by Algebra II or Precalculus high school courses. 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?

For people coming from a math background, the most important thing to remember is that physics competitions aren't like math competitions. The reason is that 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.

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 topics like Euclidean geometry which rarely come up in higher mathematics, but can be scaled up to arbitrary difficulty; thus, advanced classes don't usually help. By contrast, physics competitions were invented to spark interest in higher physics. Climbing from the $F = ma$ to the IPhO will take you on a tour through some of the greatest ideas in physics, from the problems that Newton solved to recent Nobel prizes. A decent theoretical physics graduate student would know how to solve IPhO problems, and that's a good thing – it means you are learning important things about reality by doing them.

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 deeper knowledge. 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.

How do I start learning physics?

The most common and best way to start learning physics is from your high school physics teacher!

What if I don't have a physics teacher, or want to start earlier?

You're in luck, because there are more resources for learning physics independently now than ever before. You can get full course materials for free from MIT OpenCourseWare or Coursera. Many homeschoolers enroll in Stanford's Online High School, which provides a structured curriculum. If you're self-motivated, the most comprehensive option is to study from a good book, listed below.

If you're just starting out, I strongly advise against using any resource that isn't designed as a cohesive whole. 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.

The same problem occurs for 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 legitimate, 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. I wasted countless hours like this at a young age, wondering why somebody didn't just organize the material consistently. Only later did I realize that this is literally what books and courses are.

Of course, books and courses also vary widely in quality, and it's important to avoid getting stuck on a poor one just because it happened to be free and high in the Google results. To understand why, you have to consider how good textbooks are created in the first place. Usually, a teacher will start a course using a standard 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.

The active ingredient in this process is the *students*, who push the teacher to improve their materials year after year. All of the books and courses I recommend in this document were made this way. Those that weren't tend to be plagued with issues, such as constant typos, trivial or nonsensical problems, huge jumps in difficulty, and crucial omissions. So the basic question you want to ask yourself when looking at a resource is: was it ever tested? Have students actually been able to use it to learn things from scratch? If they found problems, could they ever get corrected? Unfortunately, this criterion rules out the vast majority of free textbooks and YouTube videos.[1]

[1] If a professor was reading this, they would probably complain that I'm underrating the benefit of expert review. That's true too: books can have serious problems that are hard to detect by students. For example, the 2000-page online book Motion Mountain looks alright at first: volume I is light on math, but full of neat examples. But it's

Anyway, if you don't already know 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. Now, mathematicians often complain that these books aren't rigorous enough, and prefer books like Spivak's. But Spivak gives students little practice with actually doing the kinds of computations that come up in physics, and getting through it can take quite a while, since it starts by proving basic propositions like $1 > 0$ and $1 + 1 \neq 0$. If you're interested in mathematical rigor, I think a good compromise is the Art of Problem Solving calculus book, which has both reasonable proof sketches and challenging computational problems.

Once you know the basics of calculus, such as derivatives and single integrals, you're ready to start calculus-based physics. If you want video lectures, my top recommendation is Yale's Fundamentals of Physics courses. 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 taken down now, as its new owners try to figure out how to make money from them.

The main 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 conclusively shown that this works better for the average student, because people tend to zone out during traditional lectures. If you're motivated enough to be self-studying, that probably doesn't apply to you, but I think the core insight is right: you don't really need lectures when the great books listed below are available.

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

I'll let you in on a secret: there are standard benchmark exams used in physics education research which have been designed over years to measure exactly this, for the purpose of evaluating new teaching methods. Examples include the Force Concept Inventory and the Conceptual Survey of Electricity and Magnetism. (Of course, they only work for research if people haven't seen them beforehand, but I think there are few enough people reading this that it won't matter.)

Find these exams online. If you understand basic mechanics and electromagnetism, you should be able to get above 90% on the FCI within 30 minutes, and above 80% on the CSEM within 45 minutes. If you can't do this, you likely have misconceptions that you should resolve before doing anything else! The newly redesigned AP Physics 1 and 2 exams are also a good benchmark; these cover mechanics and everything else, respectively. If you can't comfortably score a 5 on AP Physics 1, your mechanics isn't in good shape.

What are some good introductory books at each level?

There's a robust ecosystem of physics textbooks, with many good options. The recommendations I give below are pretty standard; for more data, you can consult AIP's survey of physics teachers.

full of intuitively plausible but slightly wrong statements which fall apart in more general situations, reflecting the author's lack of technical expertise. This problem steadily gets worse: volume IV is an oversimplified introduction to quantum mechanics which contains serious errors on almost every page, volume V covers a bizarre mix of particle physics, consciousness, and sexual reproduction, and volume VI is the author's personal theory of everything. Because the change is gradual, a student can get seriously misled without noticing, like the proverbial boiling frog. So maybe a useful second criterion is that the book should have been used for an official course at a decent university.

- For basic algebra-based physics, some commonly used books are *Holt Physics*, *Physics Principles and Problems*, *Conceptual Physics* by Hewitt, and *Physics: Principles with Applications* by Giancoli. If you want to start here, I recommend the last two. 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. Neither are enough for physics competitions, but they'll set a good foundation. If you're comfortable with calculus, you can probably skip this level entirely.
- For basic calculus-based physics, there are many books, such as the ones by Giancoli, Knight, Serway and Jewett, Tipler and Mosca, Sears and Zemansky, 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. They are also all about equally good, though I would recommend Serway and Jewett if you had to choose one.
- For more advanced calculus-based physics, I strongly recommend *Physics* (5^{th} edition) by Halliday, Resnick, and Krane. This book is used in college honors courses, and has significantly more challenging problems, which were edited by a past director of the USAPhO. The explanations are very clear, and I know many people who have succeeded using it.

For historical context, the modern era of introductory calculus-based physics textbooks in the United States was started by Halliday and Resnick in 1960, as part of a societal push for STEM education in the wake of Sputnik. It became so popular that all the other calculus-based textbooks listed above are just watered down descendants of it (i.e. taking topics out, but never adding any new topics in), which explains why they're so similar. Even Halliday and Resnick itself has been watered down: *Fundamentals of Physics* by Halliday, Resnick, and Walker is essentially *Physics* with the most advanced third of each chapter removed.

When shopping for these books, you might notice that they come in many editions, sometimes more than 10, and that the latest edition costs much more than the rest. In general, there is very little difference between the most recent edition and the previous three. The purpose of making so many editions is to prevent students from saving money by buying used books, since courses generally require students to have the latest edition.[2] If you're self-studying, there's no need to buy the latest edition. An exception is Halliday, Resnick, and Krane, since many new questions were added in the 5^{th} edition, including all of the very useful multiple choice questions.

There are also many supplemental books made specifically for test preparation, such as Schaum's outline series, and the Princeton Review, Barron's, and 5 Steps to a 5 series. I don't recommend using any of 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 possible 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 make you unable to answer any question deeper than a one-step plug and chug.

How much time will it take to qualify for USAPhO/qualify for USAPhO 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.

[2] Don't blame the authors, it's not their choice. It's because introductory books are a lucrative, sketchy business.

- 9th grade summer: I don't recall learning anything. I grinded a lot on RuneScape, with occasional breaks to practice for math competitions.
- 10th grade: I took a standard calculus course in school, and a standard algebra-based introductory physics course, with great teachers in both. I didn't do any 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. This background was enough to qualify for the USAPhO, but not enough to do any of the questions on it.
- 10th grade spring/summer: I self-studied calculus-based physics by reading the even more mediocre 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.
- 11th grade: I read the awesome Halliday, Resnick, and Krane throughout the year, mixing in past $F = ma$ exams in January and past USAPhOs in the spring. I worked roughly 10 hours a week, for about 250 hours in total. That year I qualified for camp 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. You just need to get the basics down, and spend about one year learning on top of that. And this isn't just my experience. When we ask students who qualify for camp to describe their journey, they usually say something very similar. They learn physics for a year, or maybe two if they have a lot of other things going on. Prep courses are common, but most just take only one such course, or read just one good textbook. Some don't even prepare at all; they build their skills by following their curiosity.

What makes a competition prep program effective?

The main thing that makes a prep program effective is the student.[3] The simple fact is that if a student isn't engaged, then prep programs are useless at best. 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 hours of experience, and not very high-quality ones at that. If practice stops entirely once the class ends, most of that knowledge will be quickly forgotten.

Compare this to what I listed above: 400 hours accumulated over a 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.

You might think prep programs can cut down the hours needed because they "teach to the test". This is a myth. Even the $F = ma$ exam requires a broad understanding of mechanics. It's certainly possible to characterize the solutions to individual $F = ma$ problems as "tricks", but if you don't have a foundation, there will be an overwhelmingly large number of tricks for you to memorize, and they'll be ten times as hard to remember because you won't know where they come from.

If that doesn't convince you, think about learning an instrument, playing a sport, or learning a language. Do football players cram in eight hours of practice the day before a big match? Have you ever seen a pianist who got anywhere on an hour a week of practice? Of course not, and learning physics (yet another language) is no different. There is no secret. You just have to engage.

[3] By the way, one thing that can certainly never make a prep program effective is the *parent*. I sometimes see parents spend more energy dragging their kid through prep classes and books than their kids spend actually thinking about physics. Sometimes parents 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.

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!

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 most equations in physics 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 $F = ma$, where many questions require the test taker to think 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. In fact, this might end up taking *longer* if you try to do it without calculus. 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 school physics curriculum has a lot of things that don't really make sense. For example, you are told to remember that there are precisely 3 kinds of lever, 4 states of matter (or was it 5?), and 6 kinds of simple machine. Or that when you round numbers, you should round to the closest digit, unless you're rounding a 5, in which case you should round to an even digit, unless the number was negative.[4] In some schools, you must remember that the pound is really a unit of mass; the unit of weight is called the pound-force. In other schools, you must remember that the pound is really a unit of weight; the unit of mass is called the pound-mass. In some schools, you must do multiplication and division from left to right, so that $1/2 \times 3 = 3/2$. In other schools, you must do multiplication before division, so that $1/2 \times 3 = 1/6$. In yet others, division comes first.

When I was in middle school, 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. Thankfully, none of this has much relevance to the Olympiad, or physics in general. It is only repeated in school curricula out of habit.

The 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.[5] The reason the rules don't even agree from school to school is that

[4] I'm just making up a rule here; different schools teach different ones! I once saw a quiz that was entirely focused on these edge cases: every other question involved a negative number ending in 5. The point was presumably to check the students knew all the rules, but the result was that it focused on only the most useless ones.

[5] In the final exam of an introductory mechanics course, the great physics education researcher Edward Redish once asked his students what the most important equation in mechanics was. The most common response was not

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, my advice is to grit your teeth, grudgingly learn it just well enough to maintain decent grades, and immediately forget it.

Of course, some of the arbitrary-looking stuff you learn in school actually does turn out to be important. For example, you'll probably have to learn a lot of rules for manipulating matrices, which seem 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.

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

The main ingredient for success is a solid understanding of mechanics, which you should get from a book like Halliday, Resnick, and Krane. You should also prepare for the format and quirks of the $F = ma$ exam, but don't get the priority flipped: specific preparation should take a couple dozen hours at most, while learning the foundations takes hundreds of hours.

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 almost 20 past $F = ma$ exams publicly available, which gradually increase in difficulty over time. After completing past $F = ma$ exams, you should immediately check against the answer key, or the more refined official solutions manual, both of which are also publicly available, and understand the solution to any question you missed. 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. There are also old $F = ma$ exams going back to 1997 available for purchase on the AAPT website. However, all these competitions are significantly more straightforward, and some contain non-mechanics questions. I think it's best to just make the most of the $F = ma$ exams.

Sir, what are your tips to crack JEE?

I get a lot of questions from Indian students asking about the INPhO, JEE Mains, or JEE Advanced, but I really can't help, because Indian competitions 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 optics, circuits, nuclear physics, and fluid dynamics. Second, because the exams have almost a million participants, they are very competitive. I don't think their questions are harder than those of American or East Asian competitions, but they demand extreme precision, since the time limits are short and partial credit is almost nonexistent.

In my opinion, this degree of competition harms actual learning. For example, students often speak of neglecting "theory" to cram in more practice with "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, it's common to study problem solving *without* theory, in the sense that you just memorize a lot of procedures for solving standard

$F = ma$ or even $F = GMm/r^2$, but $d = at^2/2$, and you can probably guess why.

problems without asking why they work. Maybe that's what the average student has to do to succeed in such exams, but it's not ideal.

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

There are a few basic principles that almost everyone, from teachers to education researchers to bloggers, agree on.

- 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 the logical development of the idea – what assumptions do you need to get from one equation to another? Take limiting cases of the equations, and try to relate them to ones you already know. Make sure you can reconstruct the idea, or at least the intuition for it, from scratch.
- All that matters is that you properly chew and digest the ideas. Everybody has their favorite way of doing this. Some people swear that you have to handwrite your notes, not type them; some old folks might tell you the only *real* way to learn is to write cursive with a fountain pen. I write my notes in bulleted lists, but others prefer web-like structures such as mind maps, and yet others never take notes at all. Some people swear by books and others swear by lectures. Some people keep their books pristine and others highlight every word. I love explaining things verbally, while others prefer visualization. None of these details really matter. Use whatever method you like best, and it'll work as long as it keeps you engaged with the ideas.
- 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.
- Do practice problems that are at or just above your current level. They should be hard enough to require your full attention, but not so hard that you spend long stretches of time making no progress. Don't peek at solutions until you give each problem a good try. (If you need to peek at the solutions for more than half of the problems you're attempting, they're too hard.) When you finish doing a practice problem, reflect on what went well or poorly, and if you weren't able to do it, figure out the crucial steps you were missing.
- Make sure your studying is healthy. Long cram sessions aren't effective. Take regular breaks and use them to stretch your legs. Sleep at least 7 or 8 hours a day, 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?

Halliday, Resnick, and Krane has a total of 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 an average of 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, I recommend spending 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.

On the other hand, it probably isn't worthwhile to do all of the exercises, since many reduce to plugging numbers into standard formulas. I recommend skimming to see if you know how to do them, and perhaps doing a small sample to check. On the other hand, the problems are more subtle, and form a very useful bridge from "plug and chug" problems to competition problems. I recommend reading all of the problems carefully, and doing at least half of them, depending on which strike your interest.

Answers to odd-numbered exercises and problems are at the end of the book, and a detailed instructor's solution manual to all exercises and problems can be found online. There are no answers to the multiple choice questions, but you can find my answers for the first 17 chapters here.

What's the most important trap 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, and spending all your nights and weekends grinding out busywork you don't really care about. More advanced symptoms include spending hours reading rubrics like a lawyer to argue a grade of 97% up to 98%, and jockeying for "leadership" positions in a huge array of fake clubs that don't ever do anything. In the terminal stages of this disease, you could end up founding a fake nonprofit in junior year 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 can 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!

Provided you avoided this rat race, the second biggest trap is overplanning. A lot of people get caught up on finding the *optimal* books and the *optimal* practice problems, and never actually starting to do either. Some people even make a detailed, multi-year study plan for getting an IPhO gold medal set before they learn Newton's laws, which is both a waste of time, and seriously demotivating once they realize that making a plan is much easier than doing it.

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 soccer team, gradually building up their skills while having fun. As they got better, the stakes were gradually raised, until they ended up doing daily, carefully designed practice with a coach. But it wouldn't have made sense to go looking for that coach before even learning the rules of soccer!

Long-term motivation comes from small, consistent wins, not distant goals. After an hour of learning, it is much more motivating to think "now I know why sunsets are red" or "now I know why violins have those f-shaped holes" than "now I am 0.1% closer to an IPhO gold medal". Excessive planning gives you a false sense of a distant goal moving closer, which can be exciting, but ultimately isn't good for anything. The trap is to get addicted to that *feeling* of progress, to the point that you want it more than *actual* progress. If you want to learn physics, the most important thing is to just *do* physics.

Do I have enough talent to succeed?

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 sentiments come from a good place, but they're rarely satisfying to their recipients because they're clearly not true. 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 dedicated, 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 complexity of learning things 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 suddenly 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.

Incidentally, 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 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 more time to use it; they don't stop you from doing the same.[6]

[6] Of course, the same applies if you're in college and never heard of Olympiads in high school. People seem to get insecure about this for some reason, but the point of the Olympiad is just to spark interest in physics, through some interesting elementary problems. If you're already learning advanced physics, you're not missing out!

Indeed, you shouldn't ever worry if you, or others, are ahead or behind of the "usual" track. There is nothing inherently natural about learning algebra at age 14, introductory physics at age 16, quantum mechanics at age 20, and quantum field theory at age 23. Those numbers are solely a product of history and circumstance. What you should learn next is determined by your goals and prior knowledge, not your age.

So let's say that you're interested in learning more physics. In the ideal case, this interest came from talent mediated by socioeconomic factors. You already had strong foundations in math, and when you learned basic elements of physics, whether from a physics teacher, books, or Youtube videos, things clicked for you. You saw the world in a different way, and it felt good.[7] You have some idea of what knowing more physics is like, whether it's from older adults, famous physicists, or popular science books, and you want that. You know that while people tend to say learning physics is not too practical, it's not *impractical* either; the employment prospects for physics majors are great, even though faculty positions are scarce.

If this applies to you, then if you continue learning physics, it will keep paying off. You'll continue to get "aha!" moments. You'll continue to be able to piece together, with concentrated effort, new ways of looking at the world. Of course, the *rate* at which you do this is partially determined by talent. But if you've made physical insights before, you will continue to make them in the future, provided your foundations are good. There is no wall; how far you go is up to you.

[7] This is crucial; if you don't enjoy learning physics in this way, it'll be very hard to stay motivated in the long run!