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. (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 AP Physics C (calculus-based physics) mechanics and electromagnetism tests, respectively. About 5,000 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 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 $F = ma$ exam 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 way to start learning physics is from your high school physics teacher!

What if I don't have a physics teacher yet, and want to start 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 vast amounts of time.

First, 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.

This especially applies 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.

YouTube videos have related problems. You can search for any topic in physics and find hundreds of videos where a guy records himself explaining it 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 – 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, either because it's too basic or just bad.

When I was a kid, I followed the usual 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. There's no need to stay in the shadows when you can go right to the source.

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.

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

[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 problems for generations.

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 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 shown that this works better for the average student, who would otherwise zone out during traditional lectures. 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. Book recommendations for introductory physics are listed in a separate section below.

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.

- 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,

[2] Note that Serway, Giancoli, and Knight also have other textbooks meant for calculus-based introductory physics. You might be confused why the books with the word "college" in the title are actually the less advanced, algebra-based ones. The reason is that college introductory physics has been steadily watered down for decades. In the 60s, Halliday, Resnick, and Krane was used for standard courses in average universities. Now, most colleges' introductory physics courses are at or below the level of high school algebra-based physics! These courses use "College Physics" books to say, "look, I'm totally not a high school course". Similarly, "College Math" books are around the level of Algebra II.

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.

- 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.

Like most physical things in America, introductory physics textbooks date back to 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 so successful 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. 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 10^{th} edition, while Young and Freedman is on its 15^{th}. 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 massive university systems to make their instructors require their students to get the newest edition. These changes are intended solely to prevent students from buying cheap used copies.

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 (5^{th}) edition has many very useful multiple choice questions, and some extra tricky problems. But these benefits never apply for textbooks with over 10 editions, which just tend to get more bloated with plug-and-chug problems over time. 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, there are many supplemental books made for test 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

[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.

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 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 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.

- 9th grade: I took a standard pre-calculus course in school and didn't know or learn any physics.
- 9th 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, besides making me a bit faster at algebra. As I mentioned on the first page, physics is different enough from math that you need to study for it separately.)
- 10th grade: I took standard calculus and algebra-based introductory physics courses in school, 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. I found that experience really 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.
- 10th grade spring/summer: I self-studied calculus-based physics by reading the honestly 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.
- 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.[4] 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

[4] 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.

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 $F = ma$ exam 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.

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 $F = ma$ exam, 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 American public school physics curriculum has a lot of things that don't really make sense. For example, you 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. 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. 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. And of course, it's not just an American problem. In any real electromagnetism course, the first thing you learn is that magnetic poles don't exist, but in Indian schools you are expected to memorize that the magnetic poles are real objects, located exactly $1/12$ of the way from the end of a bar magnet!

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.[5] Thankfully, none of this trivia matters for the Olympiad, or physics in general. It's cargo cult learning, which vaguely like science, but in reality conveys nothing 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, even in cases where uniform acceleration obviously doesn't apply.

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, 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[6] are still quite important at this stage in your life. My advice is to grit your teeth, learn it just well

[5] 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 boron 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.

[6] 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 easiest 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... alas, such an approach is deeply out of fashion in the United States. 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.

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 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.

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 over 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, 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. 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.

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:

- 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.

- Partial credit can be very important; you can see a past grading rubric here. To ensure that you get it, you should write your solution clearly. The logic should flow linearly down the page, and your handwriting should be readable (at least for your final answers). You don't have to rederive any standard results. You also don't have to write full sentences, but it's good to add markers to explain what you're doing (such as "by conservation of energy"). It's not mandatory, but will help you get the partial credit you deserve if your final answer was wrong.

- 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 help average students reliably solve plug-and-chug problems. They don't apply to the USAPhO, which has nontrivial problems.

- 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 25% of the points, and almost no students get above 75%. Therefore, in the modern USAPhO with its 6 equally weighted questions, a *very* rough guide is that 1 full question gets you an honorable mention, 2 gets a bronze medal, 3 gets a silver medal, and 4 gets a gold medal. (Of course, you can also accumulate these points through partial credit.) You definitely don't have to solve everything.

Sir, what are your tips to crack JEE?

I get a lot of questions from Indian students along these lines, 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 elementary mechanics, optics, circuits, and nuclear physics. Second, because the exams have almost a million participants, they are very competitive. I don't think their individual 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 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. India is an enormous country, with many incredibly talented students, yet it performs worse in Olympiads than much smaller countries like Taiwan and Singapore. Having spoken to some Indian Olympiad team members, I suspect it's because so much societal energy is devoted to JEE prep, which rewards raw speed, and broad but shallow knowledge.

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.

- 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 invent your own. (For a deep dive into these issues from the teacher's perspective, see this paper.)

- 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 type 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.[7] 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.

[7] This is a perennial controversy in the education literature. 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. What about video lectures? You can rewind, pause, or speed up a video lecture, unlike a real lecture, but in the absence of a definite time slot you might never get around to watching it at all. The real answer is that all the methods can be good or bad; it depends on how you, personally, best absorb information. Though we can all agree that Zoom school sucks.

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 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, 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!

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 understand how to do mindless calculations like everybody else, because the intuition is what matters." 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.[8]

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 hear from students who worry about what they'll do when they someday run out of practice problems, before they've even done a single one. Some people even make a detailed, multi-year study plan for getting an IPhO gold medal 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

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

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 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 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.[9]

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 12, 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.[10] (Plus, tons of kids could zoom right past them if they got to spend their early years actually learning, instead of making cutesy crafts.) 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. Let's say that you had a good foundation in math, and when you learned basic elements of physics, things clicked for you. You saw the world in a different way, and it felt good.[11] Then I can assure you that 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.

[9] 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!

[10] And they get changed all the time. Under the new California state standards, tracking is removed and all students must take introductory algebra ("solve $2x + 3 = 5$", "plot $y = mx + b$") together in 9^{th} grade, to ensure that no students get ahead of others. What society views as the "right" age for algebra is a matter of politics – a case where people fight over who gets what in a zero-sum game. People argue all day about how these changes will impact statistics, from our achievement gap to our PISA ranking, but nobody seems to care about what the students actually think. If you're a bright young student, the best response is to secede. Ignore this debate, sit at the back of the class, and teach yourself whatever you want.

[11] This is really the only important point in this rambling answer. The problem with most general advice out there is that the right advice depends on the person, but each chunk of advice is written with a specific kind of person in mind. That leads to extremely one-sided treatments, with half the articles saying that anybody can do anything, to encourage smart people full of self-doubt, and the other half playing up how arduous the road is, to discourage naive optimists. How can you tell which side is meant for you? What matters is how learning physics makes *you* feel, personally. If you don't enjoy learning physics in the way described in this paragraph, the path forward will be almost impossible. But if you do, many of the difficulties will take care of themselves.