Physics Activities

Fast-Paced Competitions

Here are some fast-paced competitions you can participate in as a high schooler in the US:

- The $F = ma$/USAPhO exams are the premier physics competitions in the US. The $F = ma$ exam is a fast-paced multiple choice exam (75 minutes, 25 questions) focusing on tricky mechanics problems, while the USAPhO exam has longer problems which require written solutions (3 hours, 6 questions).
- The PhysicsBowl is a fast-paced multiple choice exam (45 minutes, 40 questions) at the level of AP Physics 1 and 2.
- The Science Bowl is an exciting buzzer-based team competition covering all fields of science. You need a team of four, preferably with everybody specialized in one or two subjects, and qualifying for the national competition can be very competitive if you live in a large state. To do well as the team's physics player, you need to be able to solve AP Physics 1 and 2 questions *extremely* quickly, and also have a good deal of general physics knowledge. If you have a lot of general knowledge about science, consider being the science player on a quiz bowl team.
- Check to see if your state has local science competitions. For example, in New Jersey you can participate in the New Jersey Science League.
- The Physics Unlimited Premier Competition is a fast-paced short answer exam (90 minutes, 4 questions) focusing on mechanics, which can also be taken internationally.
- It's important to remember that even if you're a hotshot at high school physics, there's a lot more to learn. For example, try playing arXiv vs. snarXiv to see if you can even tell the titles of real physics papers from randomly generated ones.

Slower-Paced Competitions

Next, here are some slower-paced competitions, generally open internationally. These tend to have less name recognition, but they're fun and can help build long-term problem solving skills.

- KoMaL and FYKOS are Hungarian and Czech contests for high school students which issue a problem set every month. The problems in both tend to be elegant and instructive.
- The team behind FYKOS also runs the team-based Online Physics Brawl and Fyziklani competitions, which each last a few hours and have about 50 questions. Unfortunately, you'll have to stay up late to participate if you live in the US.
- The AAPT's journal, *The Physics Teacher*, publishes a monthly problem under the column "Physics Challenge for Teachers and Students". The difficulty is usually between an $F = ma$ and a USAPhO problem.
- The Physics Unlimited Explorer Competition is a team-based, two week competition where students explore an open-ended problem and write a research paper-style report.

- The High School Mathematical Contest in Modeling and MathWorks Math Modeling Challenge are team-based, one to two day competitions where students make are faced with an open-ended real-world problem and write a report issuing policy recommendations.
- The Online Physics Olympiad is a team-based, several day competition written entirely by high schoolers. Because it's student written, the problems can be ambiguous or difficult to understand. But the contest also has fresh ideas and comes with a great deal of excitement. In 2020, it was one of the largest international physics competitions held, with about 350 teams.
- The Physics Cup is an extremely difficult competition with one question per month, with a hint released per week. The problems are very instructive, and range from applied physics to almost pure mathematics. They always are clearly posed and have unambiguous answers, but they are sometimes so hard that almost nobody can solve them even after four weeks of hints. In theory, all the problems can be solved with only high school physics. A good knowledge of Euclidean geometry tends to help.
- The Rudolf Ortvay competition is a marathon competition with about 30 questions to be solved in 10 days, requiring undergraduate physics knowledge to solve.
- The International Theoretical Physics Olympiad is a 24-hour open-book competition for teams of undergraduates. The problems tend to be deep and open-ended, and can require graduate physics knowledge or use of the research literature.

Science Fairs

You can also consider entering a high school science fair, such as ISEF or Siemens, which have great name recognition. I'm not qualified to give advice on this, since I placed at the bottom of my county's science fair – my comparison of bean growing methods, with everything bought at Home Depot, was no match against the genetic engineering projects other people showed up with, using equipment from university labs.

I will only warn you that today, science fairs don't work at all like the competitions I've listed above. In these competitions, you can do well by learning physics on your own, or in any decent school, and thinking hard about it. For competitions I never needed anything but a single, $20 used textbook, but in science fairs, you need to know people. The reason is that it's impossible to come up with and carry out a novel and important physics research project sitting on your own at home.[1] The press releases try to make it sound like the projects spring out of a flash of creative inspiration, but in reality, the projects are simply given to students by professors at universities.

Now, most professors won't even work with undergraduates in research, because they lack the background of graduate students. And high schoolers have even less background than undergrads. That means the professors that are willing to serve as research mentors are outnumbered by high school students looking for them by a factor of a hundred to one, or perhaps even a thousand to one. Given those odds, how can you find one?

In practice, there are two options: either cold email many professors and get extremely lucky, or have an "in". For example, you can be born to parents who themselves are professors, so they can hire you in their own labs, or send you to their friends' labs. Or you could just have very involved parents, who will dig into the system and fight for you. You can go to an elite high school which

[1] This is because science is a community effort. Writing a great physics paper without a deep knowledge of what physicists are interested in is like trying to write the next great Russian novel without ever having been to Russia.

has a dedicated class that mass-produces winning science fair projects. If all else fails, you can shell out for a few hours of Zoom calls with a past science fair winner, so you can ask them how they did it. These days, they charge about $9,500 for the privilege.

Even once you have a mentor, your success in a science fair hinges on external factors. When you do high school physics competitions, or research in graduate school, success is driven by internal factors: you decide how many hours to work, which avenues look promising, and what to try next. But a high schooler doing research almost never has the background or time to do the same. Unless you're one of the top few high schoolers in the country in terms of physics knowledge[2], success will only be possible if your mentor goes to the trouble of developing a very concrete, well-posed subproblem for you to work on, while they handle all the creative direction and the details that require advanced knowledge.[3] The fact that this sounds like a pretty bad deal for the mentor (whose student will soon go off to college, never to return) is precisely why you need an "in" to get one.

In my opinion, the best childhood activities are those directed as much as possible by the kids themselves. The Online Physics Olympiad mentioned above is a great example: in a year where most physics competitions were cancelled, high school students wrote, publicized, ran, and graded a massive competition on their own, with zero budget. By contrast, a science fair is by definition an exercise in appealing to adults, who craft the projects, pay for the equipment, run the fair, hear the presentations, and judge the winners. And because there is so much adult involvement, and the stakes in prestige are so high, the essential playfulness is lost. The mood is serious, or perhaps even farcical. In a scene out of Bosch, feuding parents pull strings and throw piles of money with a desperate energy, in the feverish pursuit of an Ivy League college.

Given all this, why do we place value on science fairs at all? Physics Olympiad problems are merely exercises designed to be solvable by high schoolers who learn the subject well. But the end goal of this learning to produce scientists who can produce completely new knowledge, years down the line. A good science fair project, however, purportedly shows that the student can produce new knowledge *today*. What could be a better signal of their potential?

That's the narrative, anyway, but I think an equally compelling argument could be made in the opposite direction. What are the traits of good researchers? There are many, but they certainly include a deep understanding of one subfield, a broad knowledge of all of physics, and the ability to make insights into difficult problems they've never seen before. These underlying skills are precisely what is trained by Olympiad problems, many of which illustrate the key insights behind real breakthroughs in physics.[4] If you really care about research, I think it's better to spend your high school years building the foundation that will someday make you a good researcher, rather than chasing the appearance of the final product.

I have nothing against science fair participants, and I'm friends with a bunch of national science fair winners, many of whom also did Olympiads. (Even my PhD advisor participated, winning the national science fair at 14 after making it to the US Physics Team at 13!) Without exception, the

[2] Having met some of these amazing people, a good benchmark is knowing quantum field theory well by age 16.

[3] Many of my comments are specific to physics. For example, research projects in the social sciences, or in certain areas of mathematics like combinatorics, require substantially less background. Here, a high schooler really could do novel, interesting work almost entirely independently. And if you can tinker, you can make a lot of good stuff with relatively cheap electronics. On the other hand, for biology and chemistry, university mentorship and tight guidance is absolutely necessary. You need the extremely expensive equipment in university labs, and no professor is just going to let you mess with it. If you're there, they'll be giving you very explicit instructions so you don't waste their money.

[4] This is again specific to the Physics Olympiad. It's not quite as clear for the Math Olympiad, where there is a lot of emphasis on specialized techniques in topics like Euclidean geometry and inequalities, which rarely show up in either undergraduate math or current research. By contrast, the ideas I learned while preparing for the Physics Olympiad made college a lot easier, and I still use them in day-to-day research.

national winners are dedicated and brilliant. But if you want to stand a chance to qualify for the national science fairs, and you don't already know how the game is played, you're not going to find anything useful here, or even in any book. You're not going to get anywhere with $20 or a handful of beans. You need to find the right people.

Programs

Okay, so how do you actually find the right people? This is the advice I've gathered from friends who have won national science fairs. First, you can look at organized programs.

- If you are part of an underrepresented minority group, there are many well-organized and well-funded summer programs which will take care of the process for you and let you meet a group of similar students, such as SAMS, MITES, SMASH, YRP, SSRP, and many more.
- If you're not part of such a group, many of the organized programs out there cost exorbitant amounts of money. For example, the Summer STEM Institute is a Zoom-based program run by undergraduates with no experience formulating research questions (as mentioned above, even national winners are simply given questions to work on by their mentors). While it is possible to mass-produce project ideas, especially in data science, it's highly unlikely these cookie cutter projects are worth almost $10,000.
- If you're aiming for pure math research, one excellent program is MIT PRIMES, which matches high school students with qualified mentors for free. Admissions are relatively transparent, requiring the solution of a problem set; Olympiad qualifications help.
- For general science research, the best program is RSI, which is also free. RSI is an extremely selective program, and one of its explicit goals is to allow its students to go to any selective college they want, which is achieved by very strong recommendation letters. However, because of its prestige, if you don't come from a very small state, you usually need to *already* have research experience to stand a chance of admission.
- There are also great physics summer programs that are more about learning than research.
  - ISSYP is an nearly free program covering topics in theoretical physics, held at the beautiful Perimeter Institute. QCSYS is a free program run by Perimeter's partner university, focusing on quantum cryptography.
  - SPARC is a free program which covers "applied qualitative thinking", which means an array of fun topics such as game theory, economics, and cognitive science. Though it doesn't have much to do with physics, it attracts many people in the Olympiad community and is a lot of fun, since there's plenty of free time for discussions. A major part of the application is a set of interesting, open-ended questions.
  - SSP is a relatively expensive but fun program for high school juniors. While it bills itself as a research program, the real point is community building – hanging out with friends all night in a big observatory, taking data. Admissions have a strong "personality" component.

  Zoom-based camps are much less fun than in-person camps, because all the informal socialization is lost, leaving only dry lectures. I wouldn't recommend paying money for a Zoom-based camp. I also wouldn't recommend paying for a summer camp at a prestigious university which centers around taking a standard college course; they tend to be extremely overpriced, and you can get the same knowledge elsewhere.

Starting Research

While organized programs are fun, outside of pure math, most science fair winners don't get their projects from them. The main method is reaching out to professors directly.

- The hardest stumbling block, at least for me, was realizing this is a sensible thing to try. As mentioned above, it's highly unlikely that you could do *anything* more efficiently than a professor or even a graduate student, since you are missing years of knowledge. But professors really do choose to mentor high school students sometimes, for a variety of reasons: your time is free, you could become more useful if you stick around, and they might like you for some reason.

- If you personally know a professor already, you're very fortunate; email them and skip all the advice below. Otherwise, to get started, browse the faculty listings at nearby universities. Read their biographies and websites and see what sparks your interest. Exclude any professors that are no longer taking students, such as emeriti. Consider friendly faculty who care about mentoring; a professor happy to work with undergraduates, and who publicly encourages them to apply, is much more likely to be willing to work with high school students.

- Don't be overly picky at this stage. For example, don't fall into the trap of insisting on a string theory project because you once saw a Michio Kaku video – you're not going to get anywhere. Also don't laser focus on the highest ranked university within a thousand miles. Cutting-edge research is done at hundreds of universities in the United States. The most important factor is that the university be close enough for you to regularly show up.

- Pick several professors to send a cold email to. Don't be demanding; be aware that you're asking for a big favor. Also be aware that professors typically skim through hundreds of emails a day. Your first email should briefly convey the following information:

  - Your interest in physics. Don't try to exaggerate here, because it will be obvious if you do. For example, if you've learned some quantum mechanics by reading a textbook, that's a great thing to mention. But don't say you've been dying to work on superconducting spintronics, or whatever it is the professor works on, since infancy. A decent number of professors have heard about Olympiads, so mentioning your awards can help.
  - Your ability to code. In order for a high school student to be helpful at all, the professor needs to be able to find a specific, reasonably sized task for them to do, requiring less technical background. In the vast majority of cases, this means you'll end up coding, which is an essential part of all fields of physics. If you have experience coding, even if it wasn't in physics, you should mention it.
  - The amount of time you can commit. Summer tends to be a good time to start, because you'll be free almost all the time. Don't put a hard time limit (e.g. "I need a result within 3 months for this science fair") because research doesn't work that way. Most decent projects take a year or more.

  No matter what your qualifications are, the vast majority of requests will be declined; that's normal. Remember, you only need one!

- Here are some points of email etiquette:

  - In the United States, titles generally don't matter as much as in Europe or Asia, but it's still best to address professors as Prof. Lastname and postdocs as Dr. Lastname in a first email. If they reply to you and sign off with their first name, feel free to use it.
  - Sometimes, high school students have elaborate email signatures detailing their class year, address, school, favorite color, and so on. Scrub it; nobody uses these in real life.
  - Don't send anything that demands substantial energy for the professor to parse, such as a multi-page resume with every minor honor you've ever gotten.
  - If you don't get a response in a week, your email could have just fallen down in their inbox, so you can send a single reminder. Don't send multiple reminders and don't be annoying.
- Remember that research takes a long time, and don't obsess about jumping to a final result for the science fair. You'll probably need weeks of reading and listening just to figure out the basics of what your problem is about. Sometimes, months of work will yield nothing at all!

If you stick around in your research group, you'll find that the real benefit of mentorship has nothing to do with winning the science fair. You'll gain a much deeper appreciation of how science works by being part of a real scientific community. If you work hard and show that you can be a useful part of this community, your mentor will be able to say a lot more about your abilities than a high school teacher ever could.