Syllabus

1 Using the Handouts

Each problem set comes with a lot of supplemental reading. Most of it is just for fun; you can skip all the reading if you can make progress on the handout problems. But if the basic handout problems feel very challenging, I recommend spending some hours doing background reading, and warming up with simpler problems from textbooks.

The problems are chosen so that all of them demonstrate different ideas. Every one will have a point value from **1** to **5**, reflecting the amount you'll learn from doing it. (The point value is *not* a difficulty rating; some **2** point problems are short but very tricky, while some **5** point problems are long but straightforward.) If you get 2/3 of the total points, you'll have a good understanding of the material at the USAPhO level. Students aiming at IPhO gold medals should try almost everything.

Problems marked with **[A]** are "advanced". This doesn't mean that they're trickier, but rather that they require more sophisticated mathematical techniques. These problems are less relevant to Olympiad physics but are chosen to demonstrate interesting things. Sometimes, multi-part problems will have one subpart that is significantly harder than the rest; these will be marked with stars ($\star$).

If you're interested in USAPhO preparation, you should attempt all of the USAPhO problems, while if you're interested in the IPhO, you should attempt the international-level (IPhO, APhO, WoPhO, GPhO, EuPhO) problems. However, it's valuable to try problems from all competitions. The average IPhO question does require more insights than a USAPhO problem, but the time limits are also longer, making them equally approachable. Conversely, newer USAPhO problems often introduce new ideas quickly, and can be valuable practice even for IPhO contestants outside the US.

Some problems will be marked with a clock. For the best training results, they should be done under realistic conditions, which means you should use only pencil, paper and a scientific calculator. During this time you should write a solution by hand, with the same level of detail you would for a real Olympiad. If you run out of time but you're still making progress, feel free to continue, but draw a line on your solution indicating when time ran out. Usually, the time limit will match that in the actual competition (i.e. 10 minutes per point for an international-level competition, and 22.5, 30, or 45 for a USAPhO problem), but I'll sometimes set a lower time limit if the question is relatively short, or if it revolves around a single key insight that students would get hopelessly stuck without. After finishing, check your answers and, if your solution was not complete, figure out what you missed. It's most efficient to do this check immediately, since the problem will be fresh in your mind.

For the other problems, I strongly encourage you to settle on a final answer before consulting the solutions; otherwise you run the risk of "wasting" lots of them. There's no need to write up a detailed solution for every problem, but if your rough work is particularly messy, with lots of revisions and retries, it's worth writing a solution sketch (i.e. just a short list of equations) so you know what logic led to your final answer.

If you're stuck, with no idea how to begin, I recommend peeking at one line of the solution at once. If this happens frequently, try working on an easier resource first. But if you're stuck *between* solutions, i.e. if you have more than one potential answer but aren't sure which one is right, then it is absolutely crucial to think more. The handouts are designed so that this will happen regularly to the best students. (If it never happens to you, then you're probably jumping to conclusions too quickly!) In Olympiad physics, there is very little to memorize, and solutions are often relatively short. The hardest part is often distinguishing between correct and subtly wrong arguments, and you can only learn this through practice.

2 Textbooks and Resources

For the handouts, the only mandatory textbook is:

- Halliday, Resnick, and Krane, *Physics* (both volumes). This book contains the foundational material required; you should know it forwards and backwards. The 5th edition is more expensive, but worth it for the extra challenging problems included. The handouts are written assuming that you've completed this book, or an equivalent.

In my experience coaching the American team, you can get an IPhO gold medal in the 2020s using just the theory in this book, and well-trained problem solving skills. On the other hand, it is often valuable and enlightening to learn physics more deeply. (And if you don't ever learn pieces of physics just for fun, then what's the point of doing physics at all?) Throughout the handouts, I will reference chapters from textbooks for optional supplemental reading. The most important books are:

- Kleppner and Kolenkow, *An Introduction to Mechanics*. Used at MIT, written more like a physics book. Has good problems with a practical emphasis. The 1st and 2nd editions have almost the same problems and content, so you can use either. The 2nd edition splits up some of the early chapters; problem number references in the handouts will be to the 1st edition.

- Morin, *Mechanics*. Used at Harvard, written more like a math book. Has a large stock of elegant and tricky, albeit sometimes contrived mechanics problems, with little reference to real-world physics. Also contains an excellent, careful introduction to special relativity.

- Purcell and Morin, *Electricity and Magnetism*. Does electromagnetism with vector calculus and relativity baked in. Famous for using relativity to motivate magnetism, rather than just postulating it. Has well-written problems that provide insight. The 3rd edition is a substantial improvement on the 2nd, with SI units adopted throughout and more challenging problems. (Griffiths is an excellent undergraduate electromagnetism book, but I don't recommend using it for Olympiads, since many of its problems use vector calculus techniques beyond the Olympiad syllabus. However, the handouts will contain some good, elementary Griffiths problems.)

- *The Feynman Lectures on Physics*. A wonderful source of physical insight. Most problem sets will have some chapters assigned for entertainment and enrichment. (But it is not a replacement for a standard introductory text; one should learn the material in Halliday and Resnick first.)

- Wang and Ricardo, *Competitive Physics*, used by the Singapore physics team. This is a very good supplementary text, containing clear, detailed explanations of the precisely the theory which appears on the IPhO but not in a standard introductory textbook. It is especially useful for thermodynamics and waves. On the other hand, its problems tend to be a bit mathematically complicated or contrived, and there are a decent number of typos in the solutions.

Even more advanced textbooks, at the mid-undergraduate level, are listed in my second advice file, but they are generally not helpful for Olympiads. Finally, besides past Olympiads and textbooks, problems are also sourced from the following books, which you can consult for additional practice.

- ⋆ *200 Puzzling Physics Problems* and *200 More Puzzling Physics Problems*. Brief and tricky questions, often drawn from the excellent, long-running Hungarian Eötvös competition. The first book is highly recommended; the second book is at times too mathematically contrived to be too relevant to Olympiads, but still lots of fun.

- ⋆ Handouts by Jaan Kalda. These handouts and formula sheets provide excellent training for Eastern European style Olympiads. Good solutions written by students are available here. (If you like the style of the EFPhO/NBPhO, you can find more questions from earlier rounds here. We won't use them in the handouts, but they're more straightforward than EFPhO/NBPhO problems and can serve as a good stepping stone.)

- Cahn and Nadgorny, *A Guide to Physics Problems*. A thorough collection of graduate school qualification exam problems. Many great classic problems were given on these exams, though most problems in the book are too technical to be useful for Olympiad preparation. The massive series entitled "Major American Universities Ph.D. Qualifying Questions and Solutions", edited by Yung-Kuo Lim, has more questions of this type, though they're easier on average.

- Here are some cute, ~ 100 page books which you might enjoy spending an afternoon with.
  - Mahajan, *Order of Magnitude Physics*. A nice book about dimensional analysis and estimation. *The Art of Insight* is a longer work by the same author on the same themes.
  - Lemons, *A Student's Guide to Dimensional Analysis*. Shows a good variety of examples throughout physics, with interesting historical asides.
  - Levi, *The Mathematical Mechanic*. Uses mechanical setups to find slick solutions for calculus and geometry problems.

- There are a number of compilations of Russian physics problems.
  - Irodov, *Problems in General Physics*. This is a massive list of 2,000 practice problems. Personally, I don't recommend using it for the USAPhO or IPhO, because there are too many tedious filler problems, and only the briefest of solutions. It was a great book 40 years ago because there was nothing with comparable scope, but we have better alternatives now.
  - Krotov, *Problems in Physics*. A collection of good, old Russian Olympiad problems.
  - Савченко, Задачи по Физике. This book, often transliterated as "Savchenko", is an updated and upgraded version of Irodov, with many interesting problems and less filler. It is used for training in Eastern Europe, but it has not been translated from Russian. It shares many problems with Kalda's handouts. Student-written solutions are available here.
  - Kiselev and Slobodyanin, *Russian Physics Olympiads*. This book is the modern analogue of Krotov, containing problems from 2005 to 2017, but it's hard to find a copy. Most of the tricky homework problems in PhysicsWOOT are drawn from it. If you're preparing for this kind of exam and have already gone through the EFPhO/NBPhO problems, you should do your best to find this book.

  There's also a great tradition of tough Russian problems at the university level, though unfortunately many have not been translated from Russian. For some problems accessible to first year students, see here. The Landau and Lifshitz series is also great for further study.

- Western Europe does not have a strong tradition of Olympiad physics, but there are some nice compilations of problems at the university level which can be relevant.
  - Povey, *Professor Povey's Perplexing Problems*. A collection of simple but tricky Oxford admissions interview questions with neat historical anecdotes.

  - *Cavendish Problems in Classical Physics*. Some classic problems used for second year exams in Cambridge, back when things were more hardcore.
  - Thomas and Raine, *Physics to a Degree*. A collection of well-motivated questions used for undergraduate physics training, with many real-world applications.

- Olympiad material from Asian countries is often exceptional in its depth, but unfortunately, most such resources have not been translated to English.

  - *Physics Olympiad – Basic to Advanced Exercises*, training material used by the Japanese physics team. This book contains clear explanations of basic theory, along with a useful introduction to experiments.
  - H.C. Verma, *Concepts of Physics*. This book has decent theory, and many worked examples and problems. If you're preparing for the Physics Olympiad in India, it's a good place to start, because it's comprehensive and adapted to the Indian physics curriculum. (For example, compared to HRK it has more material on optics, and includes more applied topics such as electrolysis, photometry, humidity, calorimetry, and cathode ray tubes.) Its coverage of theory is occasionally unclear, especially in the later chapters, because it sometimes throws out magic formulas and recipes without explaining what they mean or why they work. But despite these flaws, it's still a lot better than most Indian introductory books.
  - For Olympiads, I advise against using JEE cram books, such as anything by Cengage or Arihant. The theory in these books is extremely brief; they essentially list a bunch of random formulas, some of which are misleading or meaningless. The problems are short and largely rely on applying single tricks or memorized results, and the solutions often don't make sense. These books aren't written to encourage the deeper thought required to solve Olympiad problems. Some top Indian students don't even recommend them for JEE!
  - 舒幼生, 物理学难题集萃. A massive, classic compilation of problems from the former head coach of the Chinese physics team, with full solutions. As comprehensive as Irodov, but with trickier questions, and less filler. However, the problems tend to be a bit computationally intensive, with messy answers.
  - 郑永令, 国际物理奥赛的培训与选拔. A slim book by another former head coach, with a wide range of great practice problems with full solutions. There is absolutely no filler: all of the questions are tricky, with the hardest reaching beyond IPhO level. This is one of the top books used today by serious contenders for the Chinese IPhO team. It also contains descriptions of many experiments, with data.

Finally, a quick note on referencing sources. There isn't an infinite supply of clean, insightful Olympiad-level physics problems. If you exclude trivial variations or pointless complications, I would estimate only a few thousand problems are possible, and many of those are classics, which are decades or even centuries old, and have appeared in dozens of books, papers, and competitions. (Not every problem with a pulley or an inclined plane in it is "from" Morin!) Contrary to most book authors, I try to cite sources as much as possible, not because those are actually the original sources, but because they might contain helpful alternative solutions. However, I also often modify questions, by correcting errors, adding new subparts to illustrate subtleties, or removing explicit statements of things that you can figure out for yourself. So the sources I cite should serve as only a rough guide; sometimes my solutions differ substantially from theirs.

3 Olympiad Problems

You can access most of the Olympiad problems in the handouts using the following links.

- Recent USAPhO exams can be accessed here. (The solutions have been improved and corrected over the years, so you should use this link for the latest version.) We will also occasionally use pre-2007 quarterfinals and semifinals (and their solutions).
- There are collections of international exams, such as the IPhO and APhO, here and here.
- We'll also draw problems from the EuPhO, GPhO, EFPhO/NBPhO, BAUPC, BPhO, JPhO, AuPhO, IZhO, and INPhO. (For some CPhO questions, see here. If you think there's an error in a solution, consult Stefan Ivanov's errata list.)

EFPhO/NBPhO problems won't be timed, but if you'd like to compare yourself against the competitors, this competition allows about 8 minutes per point (in contrast to the 10 minutes per point in the IPhO and APhO). If you run into issues with math rendering, try downloading a local copy and opening it with a dedicated PDF viewer. If an old link doesn't work, try the Internet Archive.

4 Curriculum

An outline of the full curriculum is shown below. In all cases, the relevant material in Halliday, Resnick, and Krane is a prerequisite, and most problem sets require all of the previous ones in that topic. The 24 units most relevant to USAPhO preparation are underlined. Prior exposure to vector calculus is useful, especially for thermodynamics and electromagnetism, but not necessary.

- 2 units of problem solving.
  - **<u>P1</u>**: dimensional analysis, limiting cases, series expansions, differentials, iterative solutions.
  - **<u>P2</u>**: probability, error analysis, data analysis, estimation.
- 8 units of mechanics.
  - **<u>M1</u>**: kinematics. Solving $F = ma$, projectile motion, optimal launching. (**P1** helpful)
  - **<u>M2</u>**: statics. Force and torque balance, extended bodies, pressure and surface tension.
  - **<u>M3</u>**: dynamics. Momentum, energy and center-of-mass energy, collisions.
  - **<u>M4</u>**: oscillations. Damped/driven oscillators, normal modes, small oscillations, adiabaticity.
  - **<u>M5</u>**: rotation. Angular kinematics, angular impulse, physical pendulums. (**P2** helpful)
  - **<u>M6</u>**: gravity. Kepler's laws, rocket science, non-inertial frames, tides. (**E1** helpful)
  - **<u>M7</u>**: fluids. Buoyancy, Bernoulli's principle, viscosity and surface tension. (**M2** helpful)
  - **M8**: synthesis. 3D rotation, precession, and tricky problems.
- 3 units of thermodynamics.
  - **<u>T1</u>**: ideal gases, statistical mechanics, kinetic theory, the atmosphere. (**M7** required)
  - **<u>T2</u>**: laws of thermodynamics, quantum statistical mechanics, radiation, conduction.
  - **<u>T3</u>**: surface tension, real fluids, phase transitions, compressible flow.

- 8 units of electromagnetism.
  - **E1**: electrostatics. Coulomb's law, Gauss's law, potentials, conductors.
  - **E2**: electricity. Images, capacitors, conduction, DC circuits.
  - **E3**: magnetostatics. More circuits, Biot–Savart law, Ampere's law, dipoles and solenoids.
  - **E4**: Lorentz force. Dynamic charges, permanent magnets, solid state physics. (**M4** helpful)
  - **E5**: induction. Faraday's law, inductors, dynamos, superconductors.
  - **E6**: circuits. RLC circuits, filters, normal modes, diodes. (**M4** required)
  - **E7**: electrodynamics. More circuits, displacement current, radiation, field energy-momentum.
  - **E8**: synthesis. Electromagnetic fields in matter, and tricky problems.
- 3 units of relativity.
  - **R1**: kinematics. Lorentz transformations, Doppler effect, acceleration, classic paradoxes.
  - **R2**: dynamics. Momentum, energy, four-vectors, forces, relativistic strings. (**E4** helpful)
  - **R3**: fields. Electromagnetic field transformations, the equivalence principle. (**E7** required)
- 3 units of waves.
  - **W1**: wave equation, standing waves, music, interferometry. (**M4** required)
  - **W2**: interference and diffraction, crystallography, real world examples. (**E7** required)
  - **W3**: sound waves, water waves, polarization, geometrical optics. (**M7** required)
- 3 units of modern physics.
  - **X1**: semiclassical quantum mechanics, bosons and fermions. (**M4**, **T2**, **W1** required)
  - **X2**: nuclear, particle, and atomic physics. (**R2** required)
  - **X3**: condensed matter, astrophysics, and cosmology. (**W3** helpful)
- 5 final units.
  - "Review" problem sets for mechanics, electromagnetism, and everything else.
  - Advice for preparing for the experimental exam.
  - Extra theoretical topics, and unused theoretical questions.

My recommended path through the core 24 problem sets is **P1**, **P2**, **M1–4**, **E1–4**, **M5–7**, **T1–3**, **E5–7**, **R1**, **R2**, **W1**, **W2**, **X1**. (This reflects the technical sophistication of the problems, and also splits up the long topics.) The other units are more relevant for IPhO preparation.

For USAPhO preparation, I recommend trying all 24 core problem sets, but with less emphasis on the hardest 1/3 of the problems. If you start in September, a good pace is one problem set per week; if you start in summer, a good pace is one problem set per 1.5 weeks. Note that later problem sets tend to require more background reading and have more complex questions. Near the end of your training, you can try the 7 practice USAPhOs. I've also omitted questions from USAPhO 2000, 2001, 2003, and 2005 from the handouts, so that you can use them as full-length practice exams.

Topics fluctuate significantly from year to year, but I would estimate that on average, a bit more than half of the points on the USAPhO and IPhO are devoted to mechanics and electromagnetism, with the rest roughly evenly divided between relativity, thermodynamics, waves, and modern physics. Of these four special topics, thermodynamics and relativity tend to be a bit more common at the USAPhO. At the IPhO, problems about specific advances in modern physics are common, though many of the parts in such problems boil down to mechanics or electromagnetism.