Syllabus

1 Advice for Handouts

Each problem set has about 30 problems, ranging in difficulty up to IPhO and beyond. For background, you should know calculus-based physics at the level of Halliday and Resnick. Each problem set comes with optional supplemental reading from some of the textbooks listed below. If the subject is new to you, I recommend spending some hours doing background reading before trying the problem set, doing extra problems from the textbooks if necessary, but if you're experienced and can immediately make progress on the handout problems, you can skip the reading.

The problems are chosen so that all of them demonstrate different ideas, so you'll get more out of the handouts the more you do. Every problem 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. Common time limits will be

 – 22.5 minutes,  – 45 minutes,  – 100 minutes.

Usually, the time limit will match that in the actual competition (i.e. 10 minutes per point for an international-level competition), 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 all problems, I strongly encourage you to write up a solution of your own if possible. It doesn't matter how neat your solution is (you certainly don't have to type anything up; handwriting is probably better since it more closely resembles exam conditions), but it should be a legitimate full solution, with a fixed final answer. Otherwise, it's easier to get lazy and waste lots of problems by peeking at the official solutions too early.

2 Textbooks and Resources

We'll be using a wide variety of textbooks and resources. A comprehensive list of relevant introductory books is given in my second advice file, and relevant chapters will be mentioned in the suggested readings for each handout. (For further reading, more specialized books will be mentioned throughout the problem sets.) The most important books are:

- Halliday, Resnick, and Krane, *Physics* (both volumes). This book contains the foundational material required; you should know it forwards and backwards. Even today, a solid understanding of it is enough to get a gold medal at the IPhO, though of course more knowledge always helps. 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 first.

- 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.

- *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 an excellent supplementary text, containing clear, detailed explanations of the theory needed to bridge the gap from an introductory textbook to the IPhO, especially 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.

Besides past Olympiads and textbooks, problems are also sourced from the following books.

- ⋆ *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.

- 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 is an updated and upgraded version of Irodov, with many interesting problems and much less filler. It is commonly used for training in Eastern Europe, but it has not been translated from Russian. Many problems in Kalda's handouts are drawn from it.
  - 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 anything made to cram for the JEE, such as *Pathfinder* or books 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, 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.

I try to reference sources as much as possible, but I have often combined problems from multiple sources, corrected errors, resolved ambiguities, standardized notation, or added new subparts to illustrate deeper points. Thus, the original references 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).
- You can access past IPhO exams here and past APhO exams here. There is also a central repository of international exams here.
- We'll also draw problems from the EuPhO, GPhO, EFPhO/NBPhO, BAUPC, BPhO, JPhO, AuPhO, IZhO, and INPhO. (For some other Olympiads, see here.)

EFPhO/NBPhO problems will not 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.

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.
  - **P1**: dimensional analysis, limiting cases, series expansions, differentials, iterative solutions.
  - **P2**: probability, error analysis, data analysis, estimation.
- 8 units of mechanics.
  - **M1**: kinematics. Solving $F = ma$, projectile motion, optimal launching. (**P1** helpful)
  - **M2**: statics. Force and torque balance, extended bodies, pressure and surface tension.
  - **M3**: dynamics. Momentum, energy and center-of-mass energy, collisions.
  - **M4**: oscillations. Damped/driven oscillators, normal modes, small oscillations, adiabaticity.
  - **M5**: rotation. Angular kinematics, angular impulse, physical pendulums. (**P2** helpful)
  - **M6**: gravity. Kepler's laws, rocket science, non-inertial frames, tides.
  - **M7**: fluids. Buoyancy, Bernoulli's principle, viscosity and surface tension. (**M2** helpful)
  - **M8**: synthesis. 3D rotation, precession, and tricky problems.
- 3 units of thermodynamics.
  - **T1**: ideal gases, statistical mechanics, kinetic theory, the atmosphere. (**M7** required)
  - **T2**: laws of thermodynamics, quantum statistical mechanics, radiation, conduction.
  - **T3**: 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 doing at least half of all 24 core problem sets. (Doing each one halfway is better than doing half of them completely.) 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.