Syllabus

1 Course Structure

This course is structured around weekly problem sets, each with about 30 problems, ranging in difficulty up to IPhO and beyond. You'll learn by working on this diverse set of problems. After you finish each problem set, we'll have an online meeting to discuss it and evaluate your solutions. You should feel free to contact me at any time by chat or email to ask for clarifications or hints. Don't hesitate to do this, because this is the essential ingredient that makes tutoring better than learning from a book! You can also ask your fellow students in the course group chat.

Usually, the entirety of each class will be devoted to discussing problems; I won't spend much time introducing the basic material. For background, you should know calculus-based physics at the level of Halliday and Resnick. Each problem set will also come with recommended reading from some of the textbooks listed below. If you're already comfortable with solving the problems, doing the reading is optional, and can be skipped to save time. If the subject is new to you, I recommend spending substantial time doing background reading before trying the problem set, doing extra problems from the textbooks if necessary.

Your problem sets will be stored in a personal Dropbox folder. Official solutions to the problems will be added to the folder before each class. The solutions were written by me and the past course TAs, Gopal Goel and Sean Chen, both of whom were USAPhO campers and IPhO gold medalists.

2 Problem Sets

The problems are chosen so that all of them demonstrate different ideas, so you'll get more out of the course the more you do. That said, it certainly isn't necessary to do every problem. Every problem will have a point value from **1** to **5**, and each problem set comes with a cutoff which is roughly 70% of the point total. If you reach this cutoff, you'll have a good understanding of the material. Participants aiming at IPhO gold medals should try essentially 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.

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, these latter problems are also valuable for USAPhO contestants. Don't be intimidated by them; they are usually worth **4** or **5** points, but that's just because of their length. The difficulty per time for older IPhOs is on par with current USAPhOs, and I don't use problems that are unapproachable. Often these longer problems have a lot to teach, since they have the time to do a more complete analysis of a physical system.

Some problems will be marked with a clock. 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 for a USAPhO A, B, and full modern IPhO problem respectively. (Older IPhO questions are much shorter, and may have correspondingly shorter times.) 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.

3 Writing Solutions

You should submit your solutions within a day before class. For ease of reference, organize all your solutions for one problem set in a single PDF, and all PDFs in your Dropbox folder.

As stated above, for timed problems your solutions must be in handwritten Olympiad solution format, and scanned. For all other problems, handwritten solutions are strongly preferred, but you can also use LaTeX. (Students generally find handwriting to be faster, even if they're proficient at LaTeX, because they can work out algebra directly on the page, and easily draw diagrams.) These solutions don't have to be extremely detailed: you don't have to show all your algebra explicitly, and you don't have to restate anything written in the question. In general, I'm more concerned with the structure of the solution than the algebraic steps. That is, emphasize the ideas you used to write down the equations, as much as how you solved them.

4 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. The following books are essential, and I recommend getting a copy of all of them immediately.

- Halliday, Resnick, and Krane, *Physics*. 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.

- Mahajan, *Order of Magnitude Physics*. A nice, short book about dimensional analysis and estimation. Also see *The Art of Insight*, a longer work by the same author on the same themes.

- Kleppner and Kolenkow, *An Introduction to Mechanics*. Used at MIT, written more like a physics book. Has good problems with a practical emphasis. I recommend getting the 1st edition, not the 2nd, because the 1st edition has harder problems.

- Morin, *Mechanics*. Used at Harvard, written more like a math book. Has a large stock of elegant and tricky, if sometimes contrived mechanics problems. 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.

- Wang and Ricardo, *Competitive Physics*, used by the Singapore physics team. This book contains clear, detailed explanations of the theory needed to bridge the gap from an introductory textbook to the IPhO, especially for thermodynamics and waves. The main drawback is that many of its problems are mathematically complex but straightforward; use another book for problems.

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

- ⋆ *200 Puzzling Physics Problems* and *200 More Puzzling Physics Problems*. Tricky questions written in Eastern European style. 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.
- Levi, *The Mathematical Mechanic*. A fun book which gives slick solutions for many mechanics and calculus 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. I don't recommend using it for the USAPhO or IPhO, because it is simply too long, with many tedious filler problems. On the other hand, it is still one of the standard books in India. That means that if you're preparing for the Indian Physics Olympiad, you should absolutely use it, because the test will assume you know it.
  - Krotov, *Problems in Physics*. A collection of old Russian Olympiad problems, trickier than the average Irodov problem.
  - Савченко, Задачи по Физике. This is an updated and upgraded version of Irodov, with many tough problems. 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 theoretical depth. Unfortunately, many 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 well-written book covers the material in Halliday, Resnick, and Krane, with many worked examples and problems. It is commonly used to prepare for the Physics Olympiad in India. (However, I would strongly advise against using any source used to cram for the JEE, such as *Pathfinder* or the Cengage series. I would be surprised if anybody could learn from the extremely brief "coverage" of theory in these books. The solved problems might be alright, but just about every page of exposition has something wrong with it, and some of the "concepts" taught are misleading or even completely meaningless.)

To learn more advanced physics, see my second advice file for some good books, which will be mentioned in the suggested readings. For specific fields, the following books could also be useful.

- Agarwal and Lang, *Foundations of Analog and Digital Electronic Circuits*. An accessible book if you want to dig deeper into electrical engineering for **E6**.
- Hecht, *Optics*. A well-written, though occasionally long-winded reference for interference, diffraction, and geometrical optics, useful for **W2** and **W3**.
- Carroll and Ostlie, *An Introduction to Modern Astrophysics*. A comprehensive book for undergraduate astrophysics. It's readable with Olympiad knowledge, and will be handy for **X3**.
- Lautrup, *Physics of Continuous Matter*. An excellent book on fluid and solid dynamics with many interesting real-world examples. It uses vector and tensor calculus heavily, but could be useful if you want to deepen your knowledge of **M6**.
- If you want to write your problem sets but have messy handwriting, see this advice. On the other hand, if you want to type your problem sets but are slow at LaTeX, play TeXnique.

5 Olympiad Problems

You can access most of the Olympiad problems we'll do using the following links.

- Recent USAPhO exams can be accessed here. We will also occasionally use older quarterfinals and semifinals (and their solutions).
- You can access past IPhO exams here and past APhO exams here.
- We'll also draw problems from the EuPhO, GPhO, EFPhO/NBPhO, BAUPC, BPhO, JPhO, AuPhO, CPhO, IZhO, INPhO, and PPRDPhO. (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.

6 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. Units that are 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, experimental technique.
- 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)

The core material relevant to the USAPhO consists of two weeks of problem solving, seven weeks of mechanics, seven weeks of electromagnetism, and eight weeks of special topics, for a total of 24. My recommended path through the curriculum is **P1**, **P2**, **M1–4**, **E1–4**, **M5–7**, **T1–3**, **E5–7**, **R1**, **R2**, **W1**, **W2**, **X1**. (This ordering reflects the technical sophistication of the problems, and also splits up the long topics so you don't work on one for too long at a time.) There are six further advanced units which are more relevant for IPhO preparation. Towards the end of the year, there will be three review problem sets and eleven graded practice USAPhOs.

For USAPhO preparation, doing a fair amount of all 24 core problem sets is better than doing a smaller number very thoroughly, because prior exposure to a wide range of ideas is useful when encountering new questions. If you start in September, a good pace is one problem set per week; if you start in mid-summer, a good pace is one problem set per 1.5 weeks. Note that problem sets tend to require more background reading and have more complex questions as the course goes on.

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.