Syllabus

1 Course Structure

This course is structured around weekly problem sets. Each will have about 30 problems, ranging in difficulty from $F = ma$ to IPhO and beyond. Fundamentally, your learning will come from working on this diverse set of problems.

At the end of the week, we'll have an online meeting to discuss the problems and evaluate your solutions. Throughout the week, you can contact me at any time by chat or email to ask for clarifications or hints on the problem. 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, or the TA, in the course group chat.

Usually the entirety of the class will be devoted to discussing problems; I won't spend much time introducing the basic material. You should already know calculus-based physics at the level of Halliday and Resnick. Each problem set will also come with an assigned reading from some of the textbooks listed below. I expect you to do any necessary reading on your own, doing extra problems from the textbooks if necessary.

All of your problem sets will be stored in a personal Dropbox folder. Official solutions to the problems will be added to the folder shortly before each class. The solutions are written by Sean Chen (the current TA) and Gopal Goel (last year's TA). Both of them are USAPhO campers and IPhO gold medalists, and if you have any questions about the problems, solutions, or life in general, you should feel free to contact them.

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 60% 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; feel free to skip them.

If you're interested in USAPhO prep you should attempt all of the USAPhO problems, while if you're interested in IPhO prep 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 unreasonably hard. 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 an officially allowed 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, immediately check your answers and, if your solution was not complete, reflect on what you could have done differently.

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 Olympiad solution format, and scanned. For all other problems, you're free to write your solutions in any format you wish. Handwritten solutions are acceptable, as long as you write legibly. You can also use LaTeX, either locally or online at Overleaf. The 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. For example, in a mechanics problem you could simply write "there are four unknowns, and the four equations we will use are energy conservation, rolling without slipping, ...", and then state the answer. Often a solution to a problem doesn't have to be too much longer than the problem statement.

4 Textbooks and Resources

We'll be using a wide variety of textbooks and resources. **Be careful to get the right edition!**

- Halliday, Resnick, and Krane, *Physics*, 5th edition. This book contains basically all of the foundational material required; you should know it forwards and backwards. Even today, a solid understanding of just the material here is enough to get a gold medal at the IPhO, though of course more knowledge always helps.
- Mahajan, *Street Fighting Mathematics*. A short, useful 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*, 1st edition. Used at MIT, written more like a physics book. Also has good problems, with a practical emphasis.
- Morin, *Mechanics*. Used at Harvard, written more like a math book. Has a large stock of elegant, tricky, if sometimes contrived mechanics problems. Also contains an excellent, careful introduction to special relativity.
- Schey, *Div, Grad, Curl, and All That*. A well-written, intuitive vector calculus book, with lots of good pictures. Also see the excellent MIT OCW 18.02 lectures.
- Purcell and Morin, *Electricity and Magnetism*, 3rd edition. Does electromagnetism with vector calculus and relativity baked in. Most famous for using relativity to derive magnetism, rather than just postulating it. Has well-written problems that provide insight.
- French, *Vibrations and Waves*. A very nice and accessible exposition of mechanics waves once used at MIT. Covers the wave equation, resonance, and normal modes; doesn't spend much time on specific waves. Also see Morin's *Waves* book draft, which is somewhat more sophisticated.

- Crawford, *Waves*. An excellent book on all aspects of waves and oscillations, with hundreds of real-world examples and home experiments; slightly more sophisticated than French.
- Hecht, *Optics*. A well-written reference for interference, diffraction, and geometrical optics, if a bit too technical for the Olympiad.
- Agarwal and Lang, *Foundations of Analog and Digital Electronic Circuits*. An accessible book if you want to dig deeper into electrical engineering.
- Fermi, *Thermodynamics*. A first thermodynamics book that rigorously and methodically develops the subject; no problems.
- Blundell and Blundell, *Concepts in Thermal Physics*, 2nd edition. A second thermodynamics book, covering important applications, using multivariable calculus and statistical mechanics. Much of it will be very useful, though we'll skip the most technical parts.
- Krane, *Modern Physics*, 3rd edition. Modern physics just means everything that was done in the past hundred years, so this is an extremely broad area. Krane covers it in about the right level of detail for the Olympiad, refraining from using higher math.
- Some students have handwriting that's hard to read; if that's you, see this advice.
- *The Feynman Lectures on Physics*. A wonderful source of physical insight. Most problem sets will have some chapters assigned for entertainment and enrichment.

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

- *200 Puzzling Physics Problems* and *200 More Puzzling Physics Problems*. Excellent, tricky questions written in Eastern European style. The sequel is a bit more mathematically advanced; also fun to try, but a bit too mathematically clever to be too relevant to Olympiads.
- Handouts by Jaan Kalda. These handouts and formula sheets provide excellent training for Eastern European style Olympiads. Very different from the USAPhO, but highly recommended.
- Krotov, *Problems in Physics*. A collection of Russian Olympiad problems in typical style; a much shorter, refined version of Irodov's *Problems in General Physics*.
- Levi, *The Mathematical Mechanic*. A fun book which gives slick solutions for many mechanics and calculus problems.
- Povey, *Professor Povey's Perplexing Problems*. A collection of simple but tricky undergraduate admissions interview questions with neat historical anecdotes.
- Thomas and Raine, *Physics to a Degree*. A collection of well-motivated questions used for undergraduate physics training, with many real-world applications.
- Cahn and Nadgorny, *A Guide to Physics Problems*. A collection of graduate school qualification exam problems. Some great classic problems are here, though most are too technical to be useful for Olympiad preparation.

5 Olympiad Problems

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

- Recent $F = ma$ and USAPhO exams can be accessed here.
- As part of this training, you'll also have access to older $F = ma$ exams, quarterfinals, 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, NBPhO, BAUPC, BPhO, JPhO, AuPhO, and CPhO. (For a comprehensive, but slightly outdated list of other Olympiads, see here.)

Always **download a local copy** and open with a PDF viewer, like Adobe Acrobat, since browser PDF viewers can mess up the math.

6 Curriculum

An outline of the full curriculum is shown below. You can go through it in any order, though I strongly suggest following the order below. Towards the end of the year, we'll also have three review problem sets and eight practice USAPhO exams. Units that are especially relevant to USAPhO preparation are underlined. In all cases, the prerequisites are a strong grasp of calculus, and the relevant material in Halliday, Resnick, and Krane. Exposure to vector/multivariable calculus is useful, but not necessary.

- 2 weeks of problem solving.
  - **<u>P1</u>**: dimensional analysis, limiting cases, series expansions, differentials, iterative solutions.
  - **<u>P2</u>**: probability, multiple integrals, error analysis, data analysis, estimation.
- 8 weeks 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.
  - **<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)
  - **M6**: more dynamics. 3D rotation, gyroscopes, and miscellaneous challenging problems.
  - **<u>M7</u>**: gravity. Kepler's laws, rocket science, non-inertial frames, tides.
  - **<u>M8</u>**: fluids. Buoyancy, Bernoulli's principle, viscosity, surface tension.
- 3 weeks of thermodynamics.
  - **<u>T1</u>**: ideal gases, statistical mechanics, kinetic theory, the atmosphere. (**M8** required)
  - **<u>T2</u>**: laws of thermodynamics, quantum statistical mechanics, radiation. (**P2** helpful)
  - **<u>T3</u>**: surface tension, phase transitions, heat conduction.

- 8 weeks 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**: the Lorentz force. Charges in fields, mechanical circuits.
  - **E5**: induction. Faraday's law, inductors, generators, superconductors.
  - **E6**: circuits. RLC circuits, normal modes, diodes. (**M4** required)
  - **E7**: electrodynamics. More circuits, displacement current, radiation, field energy-momentum.
  - **E8**: synthesis. Dielectrics, magnets, electromagnetic radiation in matter.
- 3 weeks of relativity.
  - **R1**: kinematics. Lorentz transformations, Doppler effect, acceleration, classic paradoxes.
  - **R2**: dynamics. Momentum and energy, four-vectors, forces, string theory. (**E4** helpful)
  - **R3**: fields. Electromagnetic field transformations, the equivalence principle. (**E7** required)
- 4 weeks of waves.
  - **W1**: wave equation, standing waves, music, the uncertainty principle. (**M4** required)
  - **W2**: interference, diffraction, crystallography, real world examples. (**E7** required)
  - **W3**: sound waves, water waves, electromagnetic waves, gravitational waves. (**M8** required)
  - **W4**: geometrical optics, lens systems, optics and thermodynamics. (**T2**, **E8** helpful)
- 4 weeks of modern physics.
  - **X1**: semiclassical quantum mechanics, bosons and fermions. (**W2**, **T2**, **M4**, **E7** required)
  - **X2**: nuclear, particle, and atomic physics. (**R2** required)
  - **X3**: condensed matter, astrophysics, cosmology. (**W3** helpful)
  - **X4**: miscellaneous advanced topics that didn't fit elsewhere. (**ALL** required)

The USAPhO/IPhO question distribution is roughly as follows:

	USAPhO	IPhO (theory)
Mechanics	30%	25%
Electromagnetism	30%	25%
Relativity	10%	10%
Thermodynamics	15%	15%
Waves	5%	10%
Modern	10%	15%

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. There are eight further advanced units which are more relevant for IPhO preparation.