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!

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 mechanics and electromagnetism 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 this reading on your own, doing extra problems from the textbooks if necessary.

2 Writing Solutions

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 50% of the point total. If you reach this cutoff, you'll have a good understanding of the material. If you want a very solid understanding, I recommend aiming for 75%.

Longer or trickier problems typically have more points, but I also adjust points to reflect what's most important for USAPhO prep. In particular, questions involving formal math that doesn't appear on Olympiads get less points, while actual USAPhO questions get more. Don't be intimidated just because a question is worth **4** or **5** points!

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. If you run out of time, 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 IPhO problem respectively. After finishing, you should immediately check your answers and, if your solution was not complete, reflect on what you could have done differently.

For all other problems, I encourage you to learn LaTeX and use it to type up your solutions. You can do this online at ShareLaTeX or 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.

You should submit your solutions by a few hours before class, ideally by a shared Dropbox folder or something similar, so I can see all your solutions in one place. Official solutions to the problems will be released shortly after each class.

3 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. Available for free at the link.
- 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 properly, 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 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.
- 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.

- *The Feynman Lectures on Physics.* This should be your bedtime reading.

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.
- 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 and 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.

4 Olympiad Problems

You can access most of the Olympiad problems we'll do online.

- Recent $F = ma$ and USAPhO exams are here.
- As part of this training, you'll also have access to older $F = ma$ exams, plus quarterfinals and semifinals (and their solutions).
- We'll also draw problems from the IPhO, APhO, EuPhO, WoPhO, GPhO, NBPhO, BAUPC, BPhO, and JPhO.

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

5 Curriculum

An outline of the full curriculum is shown below. I've put them in my suggested order, though you can go in any order. Towards the end of the year, we'll also have a few review problem sets and practice USAPhO exams.

- 2 weeks of problem solving. Requires calculus.
  - **P1**: dimensional analysis, limiting cases, series expansions, differentials, iterative solutions.

  - **P2**: probability, multiple integrals, error analysis, data analysis, estimation.

- 8 weeks of mechanics. Requires mechanics at the level of Halliday.
  - **M1**: kinematics. Solving $F = ma$, projectile motion, optimal launching. (**P1** helpful)
  - **M2**: statics. Force and torque balance, extended bodies.
  - **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**: more dynamics. 3D rotation, gyroscopes, many tricky problems.
  - **M7**: gravity. Kepler's laws, rocket science, non-inertial frames, tides.
  - **M8**: fluids. Buoyancy, Bernoulli's principle, viscosity, surface tension.
- 8 weeks of electromagnetism. Requires electromagnetism at the level of Halliday. Prior exposure to vector calculus is helpful but not necessary.
  - **E1**: electrostatics. Coulomb's law, Gauss's law, potentials, conductors.
  - **E2**: electricity. Uniqueness, images, capacitors, conduction.
  - **E3**: magnetostatics. DC 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, nonlinear circuit elements. (**M4** required)
  - **E7**: electrodynamics. Displacement current, radiation, field energy and field 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, tensors. (**E4** helpful)
  - **R3**: fields. Relativistic electromagnetism, gravity. (**E7** required)
- 3 weeks of thermodynamics. Requires thermodynamics at the level of Halliday.
  - **T1**: ideal gases, statistical mechanics, kinetic theory, the atmosphere. (**M8** required)
  - **T2**: laws of thermodynamics, quantum statistical mechanics, radiation. (**P2** helpful)
  - **T3**: surface tension, phase transitions, heat conduction.
- 4 weeks of waves.
  - **W1**: wave equation, standing waves, music, the uncertainty principle. (**M4** helpful)
  - **W2**: interference, diffraction, crystallography, real world examples. (**E7** required)
  - **W3**: sound waves, water waves, electromagnetic waves, polarization, gravitational waves.
  - **W4**: geometrical optics, real lenses, optics and thermodynamics. (**T2**, **E8** helpful)
- 3 weeks of modern physics. Requires almost everything else.

- **X1**: semiclassical quantum mechanics, bosons and fermions. (**W1**, **T2**, **M4**, **E7** required)
- **X2**: nuclear physics and particle physics. (**R2** required)
- **X3**: atomic physics, astrophysics, cosmology. (**W3** helpful)

The core of the course consists of three eight week units: mechanics, electromagnetism, and special topics (problem solving, relativity, thermodynamics). These cover most of the USAPhO/IPhO question distribution:

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