Syllabus

1 Course Structure

The course is structured around weekly problem sets and 1.5 hour meetings. Each problem set comes with textbook reading and about 30 questions, which break down as follows.

- Exercises are routine computations intended to give you practice with the core material. Questions derived from textbooks or the $F = ma$ are typically exercises.
- Problems typically are longer, requiring extra leaps of insight or technical skill. Most USAPHO questions will be marked as problems.
- Starred problems ($\star$) are problems that are especially tricky, complex, or time-consuming. Most IPhO questions will be marked as starred problems.

If your goal is to perform well at the USAPhO, you should solve all the exercises and aim to solve most of the problems, with extra focus on the USAPhO problems. Doing starred problems as well will help bridge the gap to the IPhO level.

Some problems will be marked with a clock. They should be done under realistic conditions, which means you should use only pencil, paper and the calculator you'll use in the real thing. 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. Typical time limits will be

 – 22.5 minutes,  – 45 minutes,  – 100 minutes

for a USAPhO A, B, and full IPhO problem respectively.

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. For example, you don't have to show the procedure of plugging in numbers, and you can skip routine algebra; you also don't have to restate anything written in the question. In general, I'm more concerned with the structure of the solution than the nitty-gritty 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 go directly to the answer.

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, no matter what the question is, because this is the essential ingredient that makes tutoring better than learning from a book! The day before the class, you should send over solutions so I have time to check them over. During class I'll answer questions, discuss your solutions and how to approach the questions you missed, and if time permits, introduce the next problem set.

2 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.
- 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.
- 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.
- Levi, *The Mathematical Mechanic*. A fun book which gives slick solutions for many mechanics and calculus problems.
- 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.
- Morin, *Waves*. An incomplete book draft written in a style very similar to Morin's mechanics book. Works very well if read right after Halliday and Resnick's chapters on waves; covers the same material with a higher degree of technical sophistication. Not many problems.
- Hecht, *Optics*. A well-written reference for interference, diffraction, and geometrical optics, if a bit too technical for the Olympiad.
- 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.
- Mahajan, *Street Fighting Mathematics*. A short, useful book about dimensional analysis and estimation. Available for free at the link.
- *200 Puzzling Physics Problems* and *200 More Puzzling Physics Problems*. Excellent, tricky questions written in Eastern European style. Generally around IPhO level, if not typical IPhO 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.
- *The Feynman Lectures on Physics*. This should be your bedtime reading.

3 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, quarterfinals, semifinals, and their solutions.
- We'll also draw problems from the IPhO, APhO, EuPhO, WoPhO, GPhO, NBPhO, and BAUPC.

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

4 Curriculum

An outline of the full curriculum is shown below, to help you decide what topics to do in what order. I've put them in my suggested order, though you're free to choose.

- 2 weeks of problem solving. Requires calculus.
  - **P1**: data analysis, dimensional analysis, limiting cases.
  - **P2**: probability, error analysis, estimation, multiple integrals.
- 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, non-inertial frames, extended bodies.
  - **M3**: dynamics. Momentum, energy and center-of-mass energy, collisions.
  - **M4**: oscillations. Damped and driven oscillators, normal modes, linearization, inharmonic oscillators.
  - **M5**: rotation. Moments of inertia, rolling, rotating frames. (**P2** helpful)
  - **M6**: more dynamics. Precession, angular collisions, physical pendulums.
  - **M7**: gravity. Kepler's laws, the solar system, gravitationally bound systems.
  - **M8**: fluids. Buoyancy, Bernoulli's principle, condensation, rockets and planes.
- 8 weeks of electromagnetism. Requires electromagnetism at the level of Halliday.
  - **E1**: electrostatics. Coulomb's law, Gauss's law, divergence and gradient.
  - **E2**: electricity. Conductors, image charges, capacitors, DC circuits.
  - **E3**: magnetostatics. Biot-Savart law, Ampere's law, dipoles and solenoids.
  - **E4**: charges in fields. Some classic hybrid mechanics/electromagnetic problems. (**M3** required, **R2** helpful)
  - **E5**: induction. Faraday's law, inductors, generators.
  - **E6**: circuits. RLC circuits, nonlinear circuit elements. (**M4** required)

- **E7**: electrodynamics. Displacement current, electromagnetic waves, field energy and field momentum.
- **E8**: fields in matter. Dielectrics, reflection and refraction, magnets.

- 3 weeks of relativity.
  - **R1**: relativistic kinematics, Doppler effect, acceleration, classic paradoxes.
  - **R2**: relativistic dynamics, four-vectors, basic general relativity.
  - **R3**: relativistic electromagnetism, field transformations. (**E7** required)
- 3 weeks of thermodynamics. Requires thermodynamics at the level of Halliday.
  - **T1**: ideal gases, heat engines, statistical mechanics, kinetic theory.
  - **T2**: the laws of thermodynamics, partial derivatives, quantum statistical mechanics. (**P2** helpful)
  - **T3**: surface tension, heat transfer, and phase transitions. (**M2** helpful)
- 4 weeks of waves.
  - **W1**: the wave equation, standing waves, musical instruments, uncertainty principle.
  - **W2**: interference, diffraction, crystallography, real world examples. (**E7** helpful)
  - **W3**: sound waves, water waves, electromagnetic waves, polarization, gravitational waves.
  - **W4**: geometrical optics, real lenses, optical paradoxes. (**T2**, **E8** helpful)
- 3 weeks of modern physics.
  - **X1**: matter waves, the WKB approximation, old quantum theory. (**W1** required)
  - **X2**: atomic physics, nuclear physics, particle physics. (**R2** required)
  - **X3**: condensed matter, astrophysics, cosmology. (**T2** helpful)

Historically, the distribution of subjects 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%

Also note that the IPhO is 40% experimental physics. In all cases, general problem solving skills are essential!