ORDER-OF-MAGNITUDE PHYSICS

PHYSICS C180 (formerly C101) / Fall 2024

4 units

Lectures: 3 hours of lecture per week (1.5 hours per class), fully recorded
Bi-weekly "Real-Time Problem Solving Labs" (in lieu of lecture)
in an Active Learning Classroom (212 Wheeler)

Discussion section: 1 hour of discussion per week

Instructor: Professor Eugene Chiang
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Homework Help: 3 hours per week + by appointment
Discord internet server 24/7 asynchronous help available

Pre-requisites: Physics 7A, 7B, 7C (or Physics 5 equivalent) + preferably at least 1 Upper Division course in the Physical Sciences. Also suitable for Graduate Students

Course Description: We will learn:

– How to understand everything in the world to within a factor of 10

– How to solve real-life problems from physical first principles

– How to make ill-posed questions well-posed

– How to sketch solutions quickly and avoid long and formal derivations

All of physics—mechanics, electromagnetism, thermodynamics, and quantum mechanics—will be covered. This class will help students understand all of the physics curriculum in practical, memorable, and entertaining ways suitable for immediate application to the real world. C180 can very challenging — you will be called to use all of your physics knowledge and to create quantitative arguments from scratch.

These skills build physical intuition and are crucial for research and practically every other line of work. Physics C180 offers a Course-based Research Experience (CRE). Research involves guesswork and hunches, and this class teaches students how to guess intelligently and follow their hunches while guided by the laws of physics. We will learn how to maximize understanding from just a modicum of information—how to reason inductively (like Sherlock Holmes) and quantitatively.

This 4-unit elective can be used toward satisfying the requirements for the Physics, Astrophysics, or Mechanical Engineering Majors. The class answers the call of the 2018 Campus Strategic Plan to embed "Discovery" into the undergraduate experience: every student will discover how powerful they are when armed with physical first principles and the courage to estimate intelligently.

THINGS WE HOPE YOU WILL LEARN:

- How to decide what physical effects are important in a given situation.
- How to decide what terms in complicated equations can be dropped.
- How to sketch the solutions of equations without actually solving them.
- How to develop a physical feeling for a subject.
- How to use physics to quantitatively understand the world around you.
- How to ask good questions.
- How to stop and think before saying, "I don't know."

"It is better to have estimated and erred than never to have estimated at all."

SYLLABUS:

1. Week 1: Everyday Estimation
2. Week 2: Energy
3. Week 3: Nuclear Physics
4. Weeks 4-5: Material Properties
5. Weeks 6-7: Fluid Mechanics
6. Week 8: Bio-Mechanics
7. Week 9: Meteorology
8. Week 10: Waves and Sound
9. Week 11: Interaction of Electromagnetic Radiation with Matter
10. Week 12: Measurement of Time
11. Weeks 13-14: Information Theory

REQUIRED TEXT:

1. *Mastering Complexity: The Art of Insight in Science and Engineering*, by Sanjoy Mahajan. Free online!

RECOMMENDED TEXTS (lectures and readings will be drawn from these):

1. *The Physics of Energy*, R. L. Jaffe & W. Taylor (encyclopedic; Weeks 2–3)
2. *Gases, Liquids, and Solids*, D. Tabor (basis of the material properties component of the class; Weeks 4–5)
3. *Physical Fluid Dynamics*, D. F. Tritton (clear, with pictures; Weeks 6–8)
4. *Air and Water*, M. W. Denny (biomechanics; Weeks 6–8)
5. *On Size and Life*, McMahon & Bonnor (examples of scaling in biology; Week 7–8)
6. *Random Walks in Biology*, H. C. Berg ("to understand diffusion, this is the book."—S. Mahajan, Weeks 7–8)
7. *Consider a Spherical Cow: A Course in Environmental Problem Solving,* J. Harte. (A physicist by training, Harte has taught environmental science and OOM estimation at Berkeley for many years; Week 9)
8. *Waves*, F. Crawford, Jr. ("a very intuitive book with excellent home experiments"—S. Mahajan; Week 10)
9. *The Science of Musical Sound*, J. R. Pierce (with fun records you can play on turntables in Berkeley's Music Library; Week 10)
10. *Radiative Processes*, Rybicki & Lightman (concise and clear, Week 11)
11. *The Quantum Beat*, F. G. Major (breezy and rambling discussion of the physics underlying atomic clocks, with a sprinkling of equations; Week 12)
12. *An Introduction to Information Theory*, J. R. Pierce (how information theory underlies everything — plus the math; Week 13)
13. *Information Theory: A Tutorial Introduction*, J. V. Stone (a more informal and modern introduction; Week 13)

SUPPLEMENTAL TEXTS:

14. *Consider a Cylindrical Cow: More Adventures in Environmental Problem Solving,* J. Harte. (The sequel to a *Consider a Spherical Cow*)

15. *Back-of-the-Envelope Physics,* Clifford Swartz (concise, readable, quantitative questions and answers, written by an Oersted Medalist, as awarded by the American Association of Physics Teachers)

16. *Physics to a Degree,* E.G. Thomas (lots of advanced undergraduate physics problems with real-world applications, with quantitative answers at the back)

17. *Flying Circus of Physics with Answers,* J. Walker (a smorgasbord of physical puzzles, with qualitative answers at the back)

18. *Fluid Mechanics*, White (popular engineering text; clear and elementary)

19. *Fundamentals of Fluid Mechanics*, Munson, Young, & Okiishi (popular engineering text; clear and elementary)

20. *Modern Developments in Fluid Dynamics: An Account of Theory and Experiment Relating to Boundary Layers, Turbulent Motion, and Wakes*, edited by S. Goldstein (covers similar topics to Tritton, but denser and with beautiful pictures and graphs)

21. *The Simple Science of Flight*, Henk Tennekes (an easy read)

22. *Splitting the Second*, Tony Jones (qualitative and readable discussion of the physics of precision timekeeping)

23. *The Physics of Musical Instruments*, Fletcher & Rossing (systematically treats a universe of instruments, with derivations)

24. *Music, Physics, and Engineering*, Harry F. Olson (concise handbook on musical engineering, with formulas but few derivations)

25. *Modern Classical Physics*, Thorne & Blandford
    A book for in-depth study, after one has learned the basics

ONLINE MOVIES:

In the 1960s, the National Committee for Fluid Mechanics Films, led by Ascher Shapiro and funded by the National Science Foundation, created a set of beautiful and entertaining films on fluid dynamics, available on YouTube.

HOMEWORK AND REAL-TIME PROBLEM SOLVING LABS:

Rules (intended to maximize learning, not be discouraging or punitive):

- **Weekly problem sets, available on bcourses, 13 total**
- **Students are required to start the homework themselves before consulting others.**
- **Academic Integrity:** Use of previous solutions obtained by any means (from the web, from another student, ...) is strictly forbidden. We hold each other to the Berkeley Code of Student Conduct: each student's submitted work is theirs and represents their original thinking, and is not copied from others or from the internet (see special note about the internet below). We will not take unfair advantage of others or betray one another's trust.
- **Collaboration and Independence:** We encourage discussion between everyone! However, homework assignments must be written up independently. Sharing of solutions between students (e.g., emailing a photo of a detailed and complete or near-complete solution) is not allowed. Students are encouraged to talk (CITE your sources!), or share a sketch, or send a short text, but final solutions must use your own language.
- **DSP Accommodations:** All accommodations (e.g. extensions on homework and extra time on exams) filed with Berkeley DSP (Disabled Students Program) will be fully respected.
- **Late homework is acceptable, but only by prior arrangement with the instructor (i.e. before it is due).** The earlier one makes a request for an extension, the more likely it will be approved without fuss. We will do our best to accommodate! At the same time, we must also respect the grader's time, and the fact that later parts of the course build on earlier parts, which means we should not fall too far behind.
- **Internet Use:** Students are free to use the internet to look up information, but are encouraged not to — it takes all the fun and challenge out of doing the problems. This class teaches research skills, and in research one cannot just google the answer — otherwise it wouldn't be research! If one does use the internet, one should give a full citation just as one does for scientific papers. Merely citing a solution to a problem without showing original work will result in minimal and probably zero credit. The more quantities one pulls from the internet, the less credit one is likely to receive.
- **Bi-weekly Real-Time Problem Solving Labs:** Groups of 3 students each will be assigned randomly, with assignments refreshed every new lab. Identical problems will be given to each group at the beginning of class, and all groups will be required to derive answers by the end of class, relying only on each other and a blackboard. The instructors and GSI will be on-hand to assist.

GRADING:

Out of 100 points in the semester: 60 (Problem Sets) + 10 (Problem Solving Labs) + 30 (3-hour Closed Book Final Exam)

There is opportunity to receive extra credit by filling out the anonymous Course Evaluation. If more than 75% of the class fills out the form, then the entire class (100%) receives +1% on their final semester grade. If fewer than 75% of the class completes the evaluation, then no one in the class receives this extra credit.

A-minus or above: ≥ 90	B-minus or above: ≥ 80
C-minus or above: ≥ 70	D-minus or above: ≥ 60
F: < 60	P/NP: $\geq 60/<60$

These are guaranteed grade boundaries; actual boundaries are likely to be more generous, depending on the distribution of grades. In other words, there will be a curve, but the curve can only help (e.g. it may still be possible to receive an A-minus with a semester average of 87, if the distribution of grades varies smoothly between 90 and 87).

COURSE CLIMATE:

We are all responsible for creating a learning environment that is welcoming, inclusive, equitable, and respectful. If a student feels that these expectations are not being met, they are encouraged to consult their instructor or the GSI, or the Reader, or seek assistance from Physics Department Officers (Chair Irfan Siddiqi; Academic Coordinator Austin Hedeman; Student Services Director Claudia Trujillo) or Astronomy Department Officers (Department Chair Jessica Lu; Equity Advisor Aaron Parsons; Astronomy Undergraduate Climate Advisors Sumbal Sharif and Charlie Tolley). See also the campus Academic Accommodations website.

The general-purpose confidential 24/7 Berkeley Path to Care Center hotline is 510 643 2005.

Order-of-Magnitude Physics – Sample Problem Set

Guidelines:

- If a question appears ill-defined, it is your responsibility to define it.
- Please cite any resources used. Although you are encouraged to not use the internet, you may as long as you give full citations. The more carefully you document your solution, the more likely you will receive credit.

Quote of the week:

> "[My] view is that no important problem in physics starts out as a well-posed problem. The challenge of a physicist is not—usually—to solve the well-posed problem; it is to make the ill-posed problem well-posed."
>
> — David Hogg

Problem 1. Thalassaemia

Thalassaemia is an inherited blood disorder. Those who have thalassaemia-major do not live past childhood unless they have a bone marrow transplant. Those who have thalassaemia-minor carry the gene but do not express it. The rules for passing the gene are the usual ones following a Punnett square.

Worldwide, about 10^5 children are born each year with thalassaemia-major.

What is the probability that you have thalassaemia-minor?

Problem 2. Hot Springs

A popular form of relaxation therapy is immersion in a hot spring.

(a) **Derive a formula for the power** P **(heat energy absorbed per time) as a function of wading speed** v**.** Your answer depends on whether the flow around your body is laminar or turbulent. Decide quantitatively.

(b) After wading for a few minutes, **how much weight have you lost?** Express in lbs.

Problem 3. Shattered Glass

Derive a formula for the maximum wind speed $v_{\max}$ a glass window can withstand.

Problem 4. Babbling Brook

Derive a formula for the oscillation frequency ν of an air bubble in water.

Problem 5. Coriolis

Water going down a drain—in a sink, tub, toilet, etc.—is said to spin in opposite directions between the Northern and Southern hemispheres because of the Coriolis effect.

False urban myth or physical fact? Decide with an order-of-magnitude proof.

Problem 6. Ask Your Own Question

Ask your own question. You do not need to answer it. Credit awarded for creativity, physicality, and relevance to the world and universe.

Order-of-Magnitude Physics – Sample Lab

Guidelines:

- Find your partner(s).
- At any given time, there should be 1 "scribe" = person writing down your group's calculations on the blackboard
- The scribe has control over what to write down (and what not to write down).
- The scribe should write so that everyone on the team can see what they are writing. Everything that is written down should be agreed upon by everyone.
- Change scribes when switching to another problem, but not within a given problem.
- When you have an answer, write it down on the "Answer Board" where everyone's answers will be collected.
- If you are done, you can assist other groups.

Problem 1. Jobs

This problem is not meant to presume or intimidate in any way. Please have fun with it!

Select an academic discipline (e.g., physics, math, computer science, ...).

What percentage of people who graduate with Ph.D.'s in this subject take up faculty positions in 1 of the top 10 largest research universities in the U.S.?

Problem 2. Magnets

(a) **How does the force F between two permanent magnets scale with their separation r?**

(b) A permanent magnet induces a paper clip to become magnetized. **How does the force F between them scale with their separation r?**

Problem 3. Energy Storage

Quantify and rank in order the energy densities [in units of kWh/kg = kW · hr / kg = energy / mass] **of the following energy storage devices**:

- A chocolate bar
- A tank of gasoline
- A human being with access to water and air but not food
- A clay brick heated to just below its melting point
- A fully charged lithium-ion battery (such batteries are NOT made purely of lithium!)
- A maximally charged electrical capacitor using a dielectric spacer made of glass. Assume the weight of the glass spacer dominates the capacitor.
- A state-of-the-art carbon alloy flywheel

Problem 4. Hummingbirds Are Not Hummers

Explain why birds above a certain mass m_{max} cannot hover, and derive a formula for m_{max}.

Use the 3 laws of metabolics. For simplicity you may model the bird as a sphere.