

Introduction

Welcome to *Matter, Energy, Space, and Time*, a course that will explore our contemporary understanding of the nature of the Universe and build a foundation for more specific investigations into astrophysical phenomena. During this course we'll discuss the nature of science and measurement, review classical physics and the laws that govern the world around us, and discuss the theoretical and experimental developments surrounding the modern physics revolution of the 20th century, including the birth of quantum mechanics and relativity. While history and facts will prove invaluable as we explore this topic, our primary goal will be to understand the arguments and quantitative techniques that make the scientific understanding of the physical world so compelling. Our driving question will be “how do we know” rather than “what do we know.”

Lectures

Lecture location and time: Online via zoom, Tu/Th 9:40-11:00 Central time.

Online announcements and grades: canvas.uchicago.edu

Online discussion board: www.piazza.com - full link and access instructions will be announced during the first week.

Note that we will try to make it possible to view lectures and complete assignments asynchronously, with the exception of lab sections where you will be expected to interact with your lab group and TAs.

In general, we expect to post lecture material online ahead of time and spend a significant part of the class on problem solving and discussion, largely in break-out rooms in small groups. There will also be occasional live demonstrations.

Instructors

Lecturer: Prof. Erik Shirokoff, shiro@uchicago.edu

Office hours: nominally Thursday at 6pm central. This may change during the first week based on student feedback. Phone: 773-834-5399

Lab director: Dr. Brent Barker, bbarker@uchicago.edu

Teaching assistants: Please see the lab syllabus.

Assignments

- **Problem sets:** We will assign 5-7 problem sets (homework assignments.) These will be announced on Thursday and due Friday of the following week at the end of the day, except where otherwise announced.
- **Short video projects:** In lieu of a traditional long-form research paper, we will ask students to create a short instructional video that explores a topic related to the class. More detail and suggestions will be distributed during the second week.

- **Labs** The opportunity to acquire laboratory experience is an integral part of this course. You will be expected to complete all lab assignments and to communicate with your lab groups and TAs. A detailed lab syllabus is available on canvas.
- **Exams:** There will be two exams: one midterm and a final. These will be open book and open notes. You will have 24 hours to complete each; however, they will be designed to be completed within approximately 2 hours. The midterm will take place during a class session in the sixth week. The final will take place during the scheduled final exam times.
- **Grading:** Each assignment will be given a numerical score and the total percentage in each category then weighted as described below. Scores will be posted on Canvas. The numerical scores will then be converted to final letter grades based on the final score distribution and discussion with TAs. (In other words, grades will be “curved,” at the conclusion of the class.

I realize this is an unfamiliar process for many students, but it’s quite common in the physical sciences. Unlike static grading systems, it neither requires us to design perfect exams nor to modify our grading rubric while grading assignments. But, this means you may see lower numerical scores than you’re used to.

You will never receive a lower grade than a student who has a lower numerical score. Using this system, it is entirely possible to get an A with a score of 40%, if many people in the class achieve lower scores. My general advice is, *Don’t Panic*. But, do feel free to talk to your TAs and instructor if you’re worried about your grade or the grading policy in general.

Weighted grades, after dividing each assignment type by the maximum score will be assigned as follows:

Labs: 30%

Problem sets: 20%

Final: 20%

Midterm: 15%

Video project: 15%

- **Extra credit:**
 - Easter eggs: There will be between 2 and 4 “easter eggs” (incontextual sentences with instructions for receiving points) included in the reading. These will each be worth 3 points - roughly 1/3 of a typical homework problem - and will be added to your problem set score after the grade distribution is determined. These will not appear in problem sets, exams, practice exams, lab instructions, or the solutions to any of these. Assigned readings and other documents are fair game.

Topics

The following is a draft list of topics we will cover. However, this schedule **will change** as the class unfolds.

1. - Introductions and course details. Where we're headed. The quantified world.
2. - Metaphysics: the nature of science
3. Fermi-problems I.
4. Dimensional analysis, units, error in measurements, probability, and why this seemingly boring topic is the most useful thing we'll cover in class.
5. Newtonian physics: motion, force, momentum, energy.
6. Fermi problems II.
7. Spooky action at a distance: Gravity, electric and magnetic fields.
8. Very big and very little things: Atoms, nuclei, elements, galaxies, the universe.
9. Thermodynamics, states of matter, aether, the crises of physics in the early 1900s.
10. midterm exam.
11. The nature of light, black body radiation, atomic spectra. Fundamental questions that inspired quantum mechanics.
12. Quantum mechanics continued. Fields, forces, waves. Experimental results.
13. Decoherence, measurement theory, quantum computers, and cats in boxes.
14. Atomic bombs, lasers, and other comic-book-film spinoffs.
15. Space and time. Fields, forces, waves. Invariance in physical laws.
16. Motivations for special relativity. The history of relativity. Clocks and rulers.
17. Space-time diagrams, thought experiments, paradoxes that actually aren't paradoxes.

Books

Required textbook

There is one required book for this course:

Kumar, Manjit, *Quantum: Einstein, Bohr, and the Great Debate about the Nature of Reality*. Any edition is fine, including e-books. Used copies are readily available online. Feel free to share a copy with other students if you like. Additional readings will be distributed via the course website.

Supplemental books - introductory textbooks These assume math and physics background knowledge similar what we expect in this class, but are much more broad in scope.

Kay, Palen, Smith, & Blumenthal, *21st century astronomy, fourth edition*, at
https://www.academia.edu/10752197/21st_Century_Astronomy_Fourth_Edition

Nick Strobel's *Astronotes* free online book:
<http://www.astronomynotes.com/index.html>

The *Teach Astronomy* free online book:

<http://www.teachastronomy.com/textbook/>

Supplemental books - more advanced textbooks These will require considerably more math and physics than we will need in this course, but would make an excellent supplement for those who want more detail. A few brief passages of these will be assigned in class.

Shu, Frank *The Physical Universe*. (On reserve.)

The Feynman Lectures on Physics, Volume I.

(free at <http://www.feynmanlectures.info/>)

Working together, plagiarism

Modern science is a collaborative process; learning science should be the same. In lab work and problem sets, we encourage you to share ideas, help each other with technical details, and check each other's work. You are welcome to collaborate with your discussion partners and other classmates on assignments. Your class experience will be more productive if you interact with your colleagues.

For problem sets and exams, we expect each student to complete their final writes independently, in their own words. The specific text, equations, and diagrams or figures in your problem sets, papers, and lab reports should be unique. We understand they will probably be very similar to that of other students, but, we expect you to solve every problem on your own (after discussing it in detail with your peers).

Note that this does **not** apply to your lab assignments which will be completed as a group assignment.

Homework tips: showing your work, sanity checks, math.

In astronomy (and the physical sciences in general), knowing a fact is usually far less important than understanding the argument that supports that fact. Just as providing a well reasoned argument is essential in an essay in the humanities, providing a coherent description of your solution is essential when solving numerical problems in the sciences. We therefore make two suggestions as you approach your assignments in this class:

First, it is absolutely vital that you show your work on assignments, especially exams. A correct derivation that leads to the wrong answer, owing to an arithmetical error, will be given nearly full points. A correct answer with no work shown will receive very few points. (A correct numerical value with the wrong units or no units will be generally be considered wrong.)

Second, it's always worth pausing after answering a problem to ask, "does this answer make sense?" Are the units right? Is the number within an order of magnitude of what you would have guessed it would be? Is there some outside argument you can make that shows your answer can't possibly be right? Congratulations, you've found the first easter egg. Please send a message via email to your instructor with the word brachistochrone in the subject line to receive credit. A derivation leading to an incorrect answer, followed by a concise statement explaining why it must be wrong, will be worth significant partial credit.

When solving math problems, there are two suggestions that will make your life (and the life of your graders) easier: leave quantities symbolic as long as possible, and don't carry

around more significant digits than you need. It's a lot less writing and easier to assign partial credit if you hold off on plugging in numbers until the end. One might ask, how many digits are enough? That's a subtle question. Unless you're doing something that specifically calls for it - like subtracting two large and similar numbers from each other - keeping one more digit than the quantities you've started with is usually a good choice. If we tell you a star is 10 solar masses, reporting an answer with 12 digits isn't meaningful. When in doubt, 3 digits isn't a bad rule of thumb. If your answer has 10 digits, you'll get full credit, but you'll have wasted some time.

Conduct

The only rule in this class is that you not interfere with other students' ability to learn and engage in the class. Please treat your fellow students with respect and expect the same from your instructors.

If you experience anything in this class that makes you uncomfortable, please don't hesitate to let us know. Note that everyone involved in teaching this class is a mandatory reporter, which means that we may be required to report incidents of harassment or abuse to the university and or the police. We *are* able to discuss which kinds of hypothetical things would need to be reported and can also direct you to campus resources that are allowed to provide confidential guidance.