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."

Instructors

Location and time: 9:30-10:50, Tu/Th, Hinds 101

Instructors

Lecturer: Prof. Erik Shirokoff, shiro@uchicago.edu
Office hours: ERC 343, Mon 5-6pm, Wed 2:00-3:00, or by appointment.
Mailbox: ERC 4th floor, buttom left
Phone: 773-834-5399

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

Teaching assistants: Coming soon.

Assignments

- **Problem sets:** We will assign 6-8 problem sets (homework assignments.) These will be due Thursday in class, unless otherwise noted. Solving problems is the most important aspect of this class. I suggest devoting real effort on these.
- **Short Papers:** In leiu of a traditional long-form research paper, we will assign two mini-papers. These must each be less than 1200 words (around 2 single-spaced pages), not including citations. The topics will be an analysis of: (1) works of fictions or art that got the science wrong, (2) works of fiction or art that got the science right. A detailed assignment will be posted during the second week. Both papers will be due on the last day of class.
- **Labs** The opportunity to acquire hands-on laboratory experience is an integral part of this course. You have already signed up for a lab session, and you should expect to be available for your scheduled lab every week. A more detailed lab syllabus will be provided at the first lab.

- **Exams:** There will be two exams: one midterm and a final. The midterm will be in-class, during the 5th or 6th week. The exact date will be announced soon in class. The final will take place during the University's scheduled exam period. The exams will consist of a mix of multiple-choice questions, short-answers, and possibly some long-form questions. You will be expected to write on the exam sheets. No books or electronic devices except non-networked calculators are allowed. A sheet of equations we've used in class and useful constants will be included with the exam materials.

- **Grading:** Each assignment will be given a numerical score, divided by the highest score in the class on that assignment, and then weighted as described below. The final letter grades will then be decided based on the final score distribution and discussion with the TAs.

  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.

  Barring exceptional and very unlikely circumstances, the median score for the class will not be less than a B. It may be higher. 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, ıDon'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.

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

  Problem sets: 25%
  Labs: 20%
  Mini-papers: 15%
  Midterm: 20%
  Final: 20%

- **Extra credt:**
  - Occasionally, low-value extra credit assignments may be included in problem sets. Points from these will be added to your problem set grade *after* the grading distribution is determined.
  - 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 one 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. Fermi-problems I.
2. - Metaphysics: the nature of science, Popper, Kuhn, "the scientific method," peer review, the culture of modern science. Aristotelian physics, medieval science and alchemy, the scientific enlightenment, the solar system and the universe
3. Dimensional analysis, units, error in measurements, probability, and why this seemingly boring topic is the most useful thing we'll cover in class.
4. Newtonian physics: motion, force, momentum, energy.
5. Spooky action at a distance: Gravity, electric and magnetic fields.
6. Fermi problems II.
7. Very big and very little things: Atoms, nuclei, elements, galaxies, the universe.
8. Thermodynamics, states of matter, aether, the crises of physics in the early 1900s.
9. midterm exam, in class.
10. The nature of light, black body radiation, atomic spectra. Fundamental questions that inspired quantum mechanics.
11. Quantum mechanics continued. Fields, forces, waves. Experimental results.
12. Decoherence, measurement theory, quantum computers, and cats in boxes.
13. Atomic bombs, lasers, and other comic-book-film spinoffs.
14. Space and time. Fields, forces, waves. Invariance in physical laws.
15. Motivations for special relativity. The history of relativity. Clocks and rulers.
16. Space-time diagrams, thought experiments, paradoxes that actually aren't paradoxes.
17. General relativity.
18. Big questions, experiments in progress.

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 lab partners and other classmates on assignments. Your class experience will be more productive if you interact with your colleagues.

However, **each student must complete their final writeups independently, in their own words.** The specific text, equations, and diagrams or figures in your problem sets, papers, and lab reports must be unique. Except for shared data within lab groups, we expect every student to turn in an independent solution to every problem, and to be able to explain every step in the solution if questioned. A good rule of thumb is to talk to your peers but not look a their papers.

There are no restrictions on your use of outside materials when completing assignments. The use of textbooks and online resources are encouraged. But, we do expect that you complete every assignment in your own words without plagiarizing prior work.

In general, the most important part of solving a problem in this class will be the very first step, where you decide how to approach the problem. I encourage you to ıtry every problem for at least five minutes before you ask for help from either staff or peers. You'll learn more from that experience than you will from the algebra at the end.

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 an 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 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.