Topics in Physics: Syllabus

SPCS Summer Institutes 2019

Session 2: 16 July 2019 - 1 August 2019

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Classroom:	160-319 (Wallenberg)
Morning sessions:	9:00a-11:30a
Afternoon sessions:	12:30p-3:30p

1 Course description

Physics seeks to answer some of the most fundamental questions about reality: what is something? Why do things happen? And why do they happen the way that they do? This course is a guided tour of foundational topics in classical and modern physics, including mechanics, electromagnetism, optics, thermodynamics, relativity, and quantum mechanics; the last part of the course will survey the state of physics research today. Students in this course will participate in hands-on experiments and serious problem-solving assignments to see how experimental and theoretical physics motivate each other.

2 Learning goals and daily activities

To cover such a broad range of topics, this class will move very quickly. Students will gain broad conceptual and quantitative understanding of each topic, with the option of exploring topics of particular interest in greater depth for the final project.

This course is quite challenging, but I expect all of you will be able to rise to the occasion. While you should aim to understand all of the material to the best of your ability, the huge amount of content we will cover in such a short time makes learning a bit like "drinking from a firehose", so don't worry if you don't understand 100% of the material. However, if at any point you are confused about something, please interrupt me and ask a question!

2.1 Morning sessions (9:00a-11:30a)

The morning sessions will be an instructor-led mix of lectures, demonstrations, group problem-solving, and hands-on experiments. There will be a short ~10min break approximately halfway through each morning session. During each lecture, there will be "ask me anything" (AMA) time for students to ask any physics-related questions they can think of, regardless of the day's topic. If you've ever wanted to know whether teleportation is possible, why there are no green stars, or how the Large Hadron Collider works, that's the time to ask!

2.2 Afternoon sessions (12:30p-3:30p)

During the afternoon sessions, students will primarily work on problem sets. The assignments are designed to be challenging to complete in the allotted time to keep everyone busy, so if you don't finish in time, don't stress about it.

If you finish early, you may do extra readings, go Wikipedia surfing on relevant topics, watch supplementary videos, or clarify concepts with the TAs. If at any point you get stuck with an assignment, ask a TA or fellow student for help on how to approach the problem. Toward the end of the course, part of the afternoon session time will be reserved for working on final projects.

2.3 Class expectations

General behavior: During lecture, please refrain from disruptive behavior, including texting, social media, perusing albums of cat pictures, or curating collections of memes – save all these for the break time. This class is not a competition to see who is smartest, and students come from a variety of backgrounds, so behavior which belittles other students for asking questions is unkind and inappropriate. Your goal should be to learn as much as you personally can in these three weeks, and to help your fellow classmates along the way. (Explaining a concept to other people is often the best way to reinforce your own understanding!)

Notes: I recommend taking notes during lecture, although you are not required to do so. The concepts and equations you will need to complete the day's assignment(s) will be presented during lecture, so it is a good idea to write them down.

Questions: There are no stupid questions! If at any point you are confused about what's going on, please speak up. (Although if your question is very off-topic, just save it for the AMA portion of lecture.) Chances are if you're confused about something, other student in the class are as well, but are just hesitant to ask.

Evaluation: There are no grades for this class, but you may receive constructive feedback on some of your assignments from the TAs, myself, or your fellow students. At the end of the course, I will complete an evaluation for each student; I expect to write a glowing recommendation for each student who commits a sincere effort.

3 Assignments

In the afternoon sessions, students will complete daily problem sets, which provide a mix of theoretical, experimental, and computational physics problems. Toward the end of the course, problem sets will be shorter and remaining time should be spent working on a final project of the student's choosing.

3.1 Problem sets

Problem sets will be posted on Google Classroom after each morning session and should be completed during the afternoon sessions. To join Google Classroom, go to `classroom.google.com` and use the code `teclog`.

3.1.1 Format

Problems will be a mix of textbook-style problems of various difficulty to reinforce the material, and open-ended physics problems I have written which will require creativity and cooperation to solve. The assignments will (generally) have three parts to them:

- Practice problems, which are quick physics problems to make sure you understand the material, and should be attempted individually.
- Challenge problems, which are more difficult problems to reinforce the concepts. You may work in small groups to complete these problems, but each student should prepare and understand their own solution.

- Main activity, which is usually one or more experiments, coding assignments, or derivations. You may work in small groups for these activities, but again, each student should prepare and understand their own solutions to the problems.

I have provided approximate times for each section to the TAs, and after the time for each section is up, the class will go over the questions as a group. So that no one runs out of things to work on, there will often be too many problems to finish in the allotted time, so don't worry if you don't finish 100% of them.

3.1.2 Collaboration

If at any point you get stuck with an assignment, ask a TA or fellow student for help on how to approach the problem. Science is very cooperative by nature, so learning how to collaborate with your peers and how to admit when you are confused is an important skill to have. If you are helping another student with a problem, try to make sure they understand it, don't just give them the answer.

3.1.3 Resources and solutions

Unless otherwise instructed, you may use any resources you want to complete problem sets (Google, WolframAlpha, Wikipedia, etc.), although you are not allowed to directly search for solutions to the problems.

Solutions to each problem set will be released at 6pm each day and we can discuss any questions the class may have at the beginning of the next morning session.

3.2 Final project

During the last few days of the course, students will work on a final project related to one of the topics covered and will give a short presentation to the class about their project on the afternoon of the final day.

3.2.1 Choosing a topic

The project topic is open-ended and negotiable with the instructor, and students may work individually or in groups of up to 3 people, although group projects are expected to be more involved than individual ones. Example final project ideas include:

- Choose an interesting technology or natural phenomena and make a presentation explaining the physical principles behind it. (If you are having trouble coming up with a final project topic, I recommend doing this one.) Example topics:
  - How do optical storage disks like DVDs work?
  - The Coriolis effect
  - How do electron microscopes work?
  - What is fire?
- Code a simulation of some interesting physical system and demonstrate it to the class! Examples:
  - Compute the evolution of an N-pendulum system
  - Simulate heat dissipation in an object over time
  - Simulate a game of pool (or ideal gas collisions)
- Choose a physics topic that is interesting to you, like black holes, the twin paradox, or Schrodinger's cat. Make a 5-minute video explaining the concept. Aim to be informative and engaging – MinutePhysics on YouTube is a good example for this project.
- Any project you can think of, so long as it relates to physics, represents an appropriate amount of work, and you discuss it with the instructor.

3.2.2 Time and content expectations

Final project presentations should be around 10 minutes per person. This is not a hard time requirement or limit, but since there are 180 minutes allocated for 15 final presentations, if many people start going overtime, you may be held to this limit.

The content of your final project should be centered around the physics of whatever topic you are discussing, although it is okay to briefly discuss applications or related uses. For example, if your topic is on holograms, you can spend a few minutes talking about the applications of holograms, but you should spend most of your time discussing the physics of how holography works. If you can, try to include at least one detailed calculation in your project (although some topics, such as various topics in quantum physics or general relativity, might be too technical or advanced for this, and that's okay).

If you would like, you may perform an experiment for your final project using any of the materials used for various class demos and labs. However, while you are welcome to use any of my class supplies, you are responsible for acquiring any other materials that you may need for your demo/experiment (I can't specially order supplies for any one student).

4 Schedule

Below is a schedule for topics to be covered during the course. This schedule is somewhat flexible and topics may be added or omitted as time permits.

4.1 Week 1 (7/16 - 7/19): Classical mechanics

7/16 Day 1: Introduction and preliminaries

- Morning session:
  - Introductions and ice breakers
  - Map of physics
  - Physical quantities and units
  - The 2019 SI System
  - Mathematical modeling
  - Estimation
  - Vectors and graphs
- Afternoon session:
  - Course expectations and background survey
  - Problem set
  - Activity: physics "tech tree"
  - Activity: Fermi problem contest

7/17 Day 2: Calculus, kinematics, and forces

- Morning session:
  - A gentle introduction to calculus (part 1): derivatives and integrals
  - Reference frames
  - 1D and 2D kinematics
  - Newton's laws of motion
  - Momentum and energy conservation
  - Activity: momentum transfer
  - Friction and tension
- Afternoon session:

  - Problem set
  - Experiment: iPhone kinematics

7/18 Day 3: On the subject of circles

- Morning session:
  - Work and energy
  - Circular motion
  - Angular kinematics
  - Newton's laws of angular motion
  - Torque
  - Gyroscopes
- Afternoon session:
  - Problem set
  - Derivation: gyroscopic precessional period
  - Experiment: fun with gyroscopes

7/19 Day 4: Computational physics

- Morning session:
  - Gravitation and orbits
  - Numerical integration, computational physics
  - An introduction to programming in Python
- Afternoon session:
  - Week 1 survey
  - Problem set
  - Experiment: coding a solar system

4.2 Week 2 (7/22 - 7/26): Early modern physics

7/22 Day 5: Oscillations and waves

- Morning session:
  - A gentle introduction to calculus (part 2): differential equations
  - Springs and oscillations
  - Waves
  - Activity: build a torsional wave machine
  - Reflection and boundary conditions
  - Phasor notation
  - Superposition and interference
  - Resonance
  - Beats
  - Demo: tuning forks and stroboscopes
- Afternoon session:
  - Problem set
  - Derivation: torsional wave equation
  - Experiment: two-speaker interference

7/23 Day 6: Electrostatics and magnetism

- Morning session:
  - Triboelectric effect
  - Activity: Van der Graaf generator
  - Coulomb's law
  - Electric fields and potential
  - Gauss's law
  - Current and voltage
  - Magnetism
  - Lorentz force
  - Motors and generators
  - Biot-Savart law
- Afternoon session:
  - Problem set
  - Experiment: simulating a cyclotron
  - Activity: build an electric motor

7/24 Day 7: Electromagnetism and optics

- Morning session:
  - A history of light
  - Electromagnetic induction
  - Electromagnetic waves
  - Maxwell's equations
  - The double-slit experiment (part 1)
  - Diffraction
  - Demo: laser tank
  - Ray optics, refraction, and Snell's law
  - Demo: total internal reflection
  - Lenses, images and magnification
- Afternoon session:
  - Problem set
  - Activity: room-scale camera obscura

7/25 Day 8: Thermodynamics and entropy

- Morning session:
  - Ideal gases
  - Demo: combustion and contraction of an ideal gas
  - Engines
  - Demo: Stirling engine
  - Carnot cycle
  - Laws of thermodynamics
  - Entropy
  - Maxwell's Demon
  - Information entropy and the Landauer limit
- Afternoon session:
  - Problem set
  - Final project proposals should be emailed to me by the end of this session

7/26 Day 9: Black hole thermodynamics

- Morning session:
  - Black holes
  - The no-hair theorem
  - Black hole information paradox
  - Hawking radiation
  - Laws of black hole thermodynamics
  - Black hole entropy
  - Bekenstein bound
  - The holographic principle
- Afternoon session:
  - Problem set
  - Work on final projects in extra time

4.3 Week 3 (7/29-8/01): Modern physics

7/29 Day 10: Relativity

- Morning session
  - Existence of the aether and the Michelson-Morley experiment
  - Special relativity and reference frames
  - Spacetime diagrams
  - Lorentz transformations
  - Time dilation and length contraction
  - Four-vectors
  - Paradoxes
  - General relativity
- Afternoon session:
  - Problem set
  - Work on final projects in extra time

7/30 Day 11: Quantum mechanics

- Morning session:
  - Blackbody radiation and the ultraviolet catastrophe
  - Double-Slit Experiment 2: Electric Boogaloo
  - The photoelectric effect
  - Wavefunctions and the Schrodinger equation
  - Quantum states
  - Superposition
  - Demo: double slit experiment
  - Measurement
  - Demo: orthogonal polarizations
  - The uncertainty principle
  - EPR Paradox + quantum entanglement
  - Quantum teleportation
- Afternoon session:

    - Problem set
    - Work on final projects in extra time

7/31 Day 12: Tour of SLAC National Accelerator Lab

- Morning session:
    - Tour: SLAC National Accelerator Laboratory
        * Important: closed-toe shoes required!
- Afternoon session:
    - Tour: SLAC National Accelerator Laboratory
    - Feedback survey
    - Work on final projects

8/01 Day 13 (full instructional day): Frontiers in physics research, final project presentations

- Morning session:
    - Choose-your-own-adventure lecture with a large assortment of possible topics:
        * Particle accelerators
        * Quantum field theory
        * General relativity
        * Quantum computers
        * Nuclear fusion reactors
        * Lasers and laser cooling
        * Nanofabrication
        * Optical information processing
        * Machine learning and neural networks
        * Complexity theory
        * Advice for pursuing physics as a career
        * (Literally any other topic you can think of that you would like to learn about)
- Afternoon session:
    - Final project presentations