Modern Introductory Physics, Part II: Classical Waves & Quantum Probabilities

*Unofficial Course Title: Classical Waves & Quantum Probabilities

*Spring 2024, Deep Springs College, **Prof. Brian Hill***

Syllabus

A **PDF of the Syllabus** containing essentially the same information as is on these web pages.

Daily Schedules

Detailed daily schedules will be kept retrospectively:

- **Daily Schedule-Term 4**

Overview

In the fall semester, we laid the foundation for quantum mechanics and nuclear physics by taking a modern approach to classical mechanics. We covered the same material as is commonly covered in the first semester of college physics, but we did it with an emphasis on three principles that transcend Newtonian mechanics:

- Conservation of momentum
- Conservation of energy
- Conservation of angular momentum

For the spring semester, we will study classical waves and quantum probabilities, focusing especially on the quantum mechanics of two-state systems, following Volume Q of *Six Ideas that Shaped Physics.* Normally one does not get to study modern physics until the sophomore year as a physics major. To get to quantum mechanics so quickly, we are short-circuiting past electromagnetism. The cost of this is that we have not encountered electromagnetic waves! So to understand quantum-mechanical systems we will first immerse ourselves in other, simple examples of waves. By the end of our quantum mechanics studies, you will be able to do probabilistic calculations using the strange mixture of deterministic time evolution punctuated by non-deterministic measurement events. You will understand how particles behave like waves, including doing all the unexpected things that waves do, such as taking many routes to a destination and exhibiting interference patterns. As a bonus topic, we will tear ourselves away from quantum mechanics, and get a brief introduction to Einstein's theory of Special Relativity. The three paradoxes in this theory will be forced upon us: (1) time dilation, (2) length contraction, and (3) the relativity of simultaneity.

The prerequisite for this class is one semester of college-level, calculus-based physics.

Text

- ***Six Ideas that Shaped Physics*, 4th Edition, Volume Q** by Thomas Moore

Grading

- 40% assignments (last semester we alternated between assignments and presentations — this semester I would like to have assignments and presentations for *every* class)
- 20% (total) for two exams in Term 4 (10% each)
- 20% (total) for two exams in Term 5 (10% each)
- 20% thorough preparation for class and leadership of course

Problem Sets / Handouts / Being Neat and Organized

There will be 10 problem sets and problem set solutions and 2 exams and exam solutions, and many handouts, and reviewing them will be valuable. To be organized, locate a three-ring binder and a three-ring hole punch, and file everything chronologically. Reverse-chronological is actually the most convenient, because you always open your binder to what you are currently working on. Problem sets should be on standard 8 1/2 x 11 paper. Multi-page problem sets should be stapled. Corrections should be erased (if done in pencil) or recopied (if done in pen). To make nice diagrams and graphs, you will very often need a ruler. The nicest technical work is facilitated by engineering pads, such as these **Roaring Spring Engineering Pads at Amazon**, and done with a mechanical pencil and with a ruler at hand. You are meant to only use one side of engineering paper. It might seem wasteful of trees and money, but it pays off in clarity and organization.

Absences (and late work)

The College's general policies on absences (and late work) are applicable. There was an email from Ryan on this on September 8, 2022 in response to a flagging Spring 2022 semester. Since that email predates half of you, the essential absence/late policies are reproduced from that email here:

Whereas missed coursework affects both your classmates and professors by lowering the thinking and understanding you bring to a given class, and interrupts the course schedule that has been set up and is adjusted on an ongoing basis with substantial care. The same is true for absences — whereas a handful of absences might be "normal" at colleges with large lectures or less serious academics, at Deep Springs we expect students to miss *no classes* save for legitimate health issues or emergencies requiring also missing labor and governance obligations. For a student wishing to submit a course assignment past its required deadline, the student may request an extension on the assignment directly from the professor 48 hours in advance. Within 48 hours of the due date, the student must request an extension directly from the Dean. Exceptions will be granted by the Dean only if the student faces unforeseen and unforeseeable circumstances. A student who misses the deadline will be penalized an amount that is roughly equivalent to a letter grade for each day the assignment is late. Assignments cannot be turned in after solutions and graded assignments have been handed back, which generally happens one to two classes after they were turned in.

Modern Introductory Physics Part IIa — Daily Schedule Term 4

Course **home page**

Week 1 — Waves — Principle of Superposition

- Tuesday, Jan. 9 — Study *Six Ideas* Q1.1 to Q1.3 — Choose a problem to present from the end of Chapter Q1 and pair up with someone to discuss both problems and then present one of your two problems jointly — Study and complete the handout/worksheet on compression waves that I set out across from the copier
- Friday, Jan. 12 — Finish *Six Ideas* Q1 — Finish "The Bridge" handout — Look ahead to *Six Ideas* Q2 Section 1 — Problem Set 1 **Due Friday**

Week 2 — Standing Waves — Interference

- Tuesday, Jan. 16 — Theory and simulation presentations for the **weakly coupled harmonic oscillator** — Torsion wave theory, **torsion wave video**, and **torsion wave animation**
- Friday, Jan. 19 — Study Six Ideas Sections Q2.1 to Q2.3 — Discussion of Problem Set 2, especially harmonics on a guitar string and modes of an organ pipe — Presentation from Group 1 on **Single-Slit interference** — Presentation from Group 2 on **Double-Slit interference** — **Problem Set 2** for Friday

Week 3 — Interference — Light is a Particle

- Tuesday, Jan. 23 — Study Six Ideas Sections Q3.1 to Q3.5 (Q3.6 is advanced) — Advanced discussion of last problem on Problem Set 3 — Presentation from Ethan (with Hexi and Miles if out of quarantine): a Python program that does the in-class exercise from the last class — Presentation from Emma on applications of Section Q3.6 to laboratory class on cloning — Presentation from Brian (looking ahead to Q4.1): **Light is a wave** and the wave theory explains the entire electromagnetic spectrum — Presentation from Trey: the ultraviolet catastrophe vs. the actual black-body radiation spectrum — **Problem Set 3** for Tuesday
- Friday, Jan. 26 — Six Ideas Q4 — Presentation from Miles on the rare condition of tetrachromacy — Presentations from Rebecca and Hexi (who will coordinate and divide the historical material): Evidence for the wave nature of light such as the explanation of Snell's Law vs. evidence for its particle nature, especially Millikan's paper from 1913 — Presentation from Ren and Miles: Problem Q4R.1 on the visibility of stars — Presentation from Brian: Prelude to **“Particles Behave Like Waves,”** Chapter Q5 — **Problem Set 4**

Week 4 — Particles Behave Like Waves — Exam 1

- Tuesday, Jan. 30 — Six Ideas Q5 — Black-body radiation and the resulting appearance of **bluish stars, white and yellowish stars, and reddish stars** — Presentations on Q1 to Q4: Emma and Ethan, Q1R.1, a slightly tricky Doppler shift problem; Hexi and Miles, Q2R.2, pulsation frequency of variable stars; Rebecca and Ren, Q3R.1, passing by foghorns; Trey, the energy levels and photon spectrum of hydrogen — **Problem Set 5** for Tuesday — Discussion of interference patterns in the first problem of Problem Set 5 — A look ahead at Q6, spin, beginning with a comparison of the units of angular momentum with the units of h
- Friday, Feb. 2 — **Exam 1**

Week 5 — Complex Variables — The Stern-Gerlach Experiment

- Tuesday, Feb. 6 — We will start into both Q6 and complex variables — Study Sections Q6.1, Q6.2 and Q6.3 of Moore — Study Sections 1-4 of Churchill, Brown, and Verhey, *Complex Variables and Applications* — Presentation from Emma, how the Balmer, Lyman, and Paschen wavelengths from Hydrogen were observed and cataloged — **Problem Set 6** for Tuesday — Lecture and handout on **Electron Spin and Magnetic Moment** — It is annoying just how many web sources there are with oversimplified versions of the Stern-Gerlach apparatus (so many that it is almost impossible to see how it is actually done) — Here is a description of an actual **MIT Stern-Gerlach lab**

- Friday, Feb. 9 — Finish studying Chapter Q6 of Moore — Study Sections 5 and 6 of Churchill, Brown, and Verhey — **Problem Set 7** for Friday — Presentations: (1) Rebecca and Ren will cover angular momentum, torque, and precession, relying substantially on Volume C, Chapter C6 of *Six Ideas;* (2) Ethan and Hexi will flesh out your understanding of magnetism, electromagnets, and the magnetic field in the Stern-Gerlach apparatus using the relevant material from Section Q6.3, photos like **this one by Dana Mason**, **this diagram and photo of a C-shaped electromagnet**, and additional illustrations and examples from **this material from a Nanhua University course**; (3) Brian will say a more about magnetic moments and then do a look ahead to Chapter Q7, **Them's the Rules**

Week 6 — The Rules for Two-State Systems — The Wave Function

- Tuesday, Feb. 13 — Study Chapter Q7 of Moore — Presentations: (1) Ren and Hexi, Q7D.3 (2) Rebecca and Emma, Q7R.3 (3) Miles and Trey, Sections Q8.4 and Q8.5, Schrödinger's cat, the multiverse interpretation of quantum mechanics! — **Problem Set 8**
- Friday, Feb. 16 — Sections Q9.1 to Q9.3 — **Problem Set 9 for Friday** (includes defining and deriving the 2x2 matrix representations of S_x and S_z) — Defining and deriving the 2x2 matrix representation of S_y — Spin-1 systems — Symmetric and anti-symmetric combinations of two spin-1/2 systems — Group velocity vs. phase velocity of the electron — A **group velocity vs. phase velocity animation** — A **waves on a pond video** — A **boat wake in a canal video** — One more **group velocity vs. phase velocity animation** — Interpreting binned vs. continuous probability distributions — Interpreting and normalizing $|\psi(x)|^2$ — The complete wave function for one electron

Week 7 — Exam 2

- Tuesday, Feb. 20 — **Exam 2** covering Problem Sets 6, 7, 8, and 9, Moore, Chapters Q6, Q7, and Q9, and Churchill, Brown, and Verhey, Sections 1-6