

AEP 4230: Statistical Thermodynamics (Fall 2025)

Instructor: Prof. Nicholas Rivera

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Credits: 4 hours

Expected study hours: About 9 hours per week (3 hours per credit) spent *outside* of class, for example on homework assignments and study of material presented in class.

Lecture Meeting Time & Location: MWF 10:10am – 11:00am, PSB 120

Discussion Meeting Time & Location: F 1:25 – 2:40pm, PSB 120

Office Hours: F 3-4pm, Clark 226

Course Description: The course starts with thermodynamics and probability and the bulk of the course is statistical mechanics, covering: classical statistical mechanics, interacting systems, phase transitions, quantum statistical mechanics, Bose and Fermi systems, and non-equilibrium phenomena such as fluctuational forces, Brownian motion, noise processes, and the fluctuation-dissipation theorem.

Course Textbooks:

- (Required) Statistical Physics of Particles, Mehran Kardar.
- (Optional) Modern Classical Physics, Kip Thorne and Roger Blandford (I will mostly pull material from Chapter 6, which is freely available online in draft form: <http://www.pmaweb.caltech.edu/Courses/ph136/yr2012/1206.1.K.pdf>).

Prerequisites: AEP 3330 (Mechanics of Particles and Solid Bodies), AEP 3610 (Introductory Quantum Mechanics), or equivalent, or permission of instructor. Some ideas from AEP 3550 (Intermediate electrodynamics) may be referenced.

Corequisites: AEP 4200 (Intermediate Mathematical Physics), or equivalent strongly recommended.

Grading:

- Prelim 1: 20%
- Prelim 2: 20%
- Final exam: 40%
- Attendance and participation: >10% (+5% extra for discussion participation).
- Homework: >10% - there will be opportunities for extra credit on assignments.

Homework: 7 problem sets throughout the course including optional problem sets. Due on Mondays at 11:59 PM, in homework box, unless otherwise stated. Feel free to collaborate with

other students. You should write up your own solutions in your own words to convince yourself that you understand the problems.

Homework policy: Late homework submissions will be accepted. If they are submitted within 24 hours of the due date (due date will usually be Monday, 11:59PM), 25 points will be deducted from your grade. Every additional day, another 25 points is subtracted (if the PSet is submitted after Wednesday, it cannot receive credit (and it will not be graded)). I cannot grant longer extensions, as solutions will be released by the end of the week. Optional problem sets cannot earn credit if they are turned in late.

Exams: *Prelim exam:* Closed-book (you can write and bring a formula sheet). Each worth 20% of the overall grade. *Final exam:* Same as the prelim but twice as long, worth 40% of the grade.

Exam dates:

- Prelim. 1: October 9, 2025, at 7:30 PM
- Prelim. 2: November 20, 2025 at 7:30 PM
- Final exam: TBD sometime during finals week; all material is fair game.

Collaboration policy: I have no issue with you discussing the homework problems with other students in the course, but you should write up your solutions independently, to ensure that you understand the logic behind each solution.

AI policy I have no issue with you using AI tools such as large language models (LLM) to help your learning, but you must not use it to generate solutions to homework problems. Beyond hallucinations which can be hard and time-consuming to verify, the exam problems will be of roughly similar difficulty to the homework problems and most of your grade comes from the exams. Your best bet on doing well is attending lecture and discussion sections, and writing up solutions to all homework problems by yourself (even if you collaborate with other students).

Course topics (subject to modification):

- 1. Thermodynamics:** laws of thermodynamics, thermodynamic potentials, minimum principles for different potentials, stability criteria.
- 2. Probability:** objective and subjective probabilities, probability densities of single-variable and multi-variable functions, cumulants, characteristic functions, central limit theorem. Information, entropy, and estimation. Important probability distributions: binomial, Poisson, normal, multivariate Gaussians.
- 3. Classical statistical mechanics:** microcanonical ensemble, canonical ensemble, grand canonical ensemble, Gibbs ensemble. Application of classical statistical mechanics to computing thermodynamic properties of example systems such as two-level systems and the ideal gas. Fluctuations from equilibrium.

- 4. Interacting particles:** Partition function of an interacting gas via cluster expansion and mean-field theory. Derivation of the van der Waals equation. Critical point behavior. Mean-field theory of magnetism. First- and second-order phase transitions.
- 5. Quantum statistical mechanics:** Failure of classical statistical mechanics for gases and solids at low temperature. Statistical mechanics and thermodynamics of phonons, photons, and collective excitations. Microstates and macrostates in quantum mechanics. Density matrices.
- 6. Random processes:** Markov and Gaussian processes, spectral densities and correlation functions, noise (shot noise, flicker noise, random walk noise), filtering, fluctuation-dissipation theorem (classical and quantum), Langevin dynamics, fluctuational forces.

**** Information can be out of date and course topics are subject to change, please confirm with instructor if you are not sure of something!**

Key Dates

Aug. 25 – First day of AEP 4230.

Sep. 1 – Labor day (no class)

Sep. 10 – PS1 due.

Sep. 22 – PS2 due.

Oct. 6 – Optional PS3 due (no late submissions allowed; solutions will be released same day).

Oct. 9 – Exam 1

Oct. 13 – Fall break (no class)

Oct. 20 – PS4 due.

Nov. 10 – PS5 due.

Nov. 20 – Exam 2

Nov. 26 – Thanksgiving break (no class)

Nov. 28 – Thanksgiving break (no class or discussion)

Dec. 1 – PS6 due.

Dec. 8 – Optional PS7 due (no late submissions allowed; solutions will be released same day).

Dec. 12-20 – Finals week. Exact date and time for final TBD.