**PHY 540 - Statistical Mechanics - Fall 2022**
**Syllabus**

**Catalog Description:** (3 credits). Brief review of thermodynamics, principles of physical statistics, systems of non-interacting particles: Boltzmann, Fermi-Dirac, and Bose-Einstein statistics. Applications to ideal gases, electrons and phonons in solids, and blackbody radiation. Approximate treatment of non-ideal gases. First-order and second-order phase transitions. Ising model, transfer matrix, and renormalization group approach. Fluctuations in thermal equilibrium, fluctuation-dissipation theorem, brief review of non-equilibrium fluctuations. Basic notions of ergodicity, classical and quantum chaos.

**Lecture:** Tuesdays and Thursdays, 8:00-9:20 AM, in ESS 079
**Instructor:** Thomas K. Allison <thomas.allison@stonybrook.edu>
**Instructor Office Hours:** Tuesdays 1 PM to 3 PM, Location TBD.
**Teaching Assistant:** TBD
**Teaching Assistant Office Hours:** TBD

**Course objectives:** Students will acquire knowledge of the fundamentals of thermodynamics and statistical mechanics, and their application to many problems across all areas of physics. Through rigorous problem solving, students will develop an intuition for connecting thermodynamic principles to atomistic phenomena and vice versa.

**Course textbooks:** *Introduction to Modern Statistical Mechanics*, by David Chandler. *Statistical Mechanics* by R.K. Pathria and Paul D. Beale.

**Other useful books:** *Introductory Statistical Mechanics*, by Roger Bowley and Mariana Sanchez. *Essential Graduate Physics, Part SM* by Konstantin K. Likharev.

**Problem Set:** The ideas behind statistical mechanics are very simple, but the applications vast and often mathematically challenging. Problem solving is then the most important component of the course. Homework problems will be assigned weekly and due on Thursdays before 5 PM in the homework box on the 5th floor next to room 577 in the Chemistry building. Please write neatly and box your answers.

Problems will often ask you to do calculations using a computer and produce plots. Always the emphasis is on elucidating the basic physics rather than computational sophistication or numerical precision. You are welcome to use whatever programming language or scientific computing software (e.g. Matlab, Mathematica, etc.) to do these problems. Please turn in a print out of your code along with the requested deliverables (e.g. the result of the calculation or relevant figures). In-class demos, starter codes, and solutions to problems using a computer will be published in Python.

**Final Exam:** Wednesday, December 7, 11:15 AM - 1:45 PM.

**Approximate Grade Weighting:** 70% problem set. 30% Final exam.

**Ambitious Summary of Contents**

*Thermodynamics fundamentals.* The first, second, and third laws of thermodynamics. Thermodynamic variables and equations of state. Helmholtz and Gibbs free energies. Maxwell relations. Stability and equilibria. Phase transitions. The Gibbs-Duhem and Clausius-Clapeyron relations.

*Foundations of Statistical Mechanics.* Probability and statistics. Ergodicity. Microcanonical, canonical, and grand canonical ensembles. The partition function and its connection to thermodynamic variables. Gibbs formula for the entropy. Chemical equilibria.

*Elementary non-interacting systems.* Classical ideal gas. Temperature-dependent heat capacity of a gas of diatomic molecules. Quantum-degenerate gasses of bosons and fermions. Electrons and phonons in solids. Blackbody radiation. Bose-Einstein condensation.

*Connecting Statistical Mechanics to Quantum Mechanics and Information Theory.* The density matrix. Mixed states and pure states. Coherence and entanglement. The von Neumann entropy and Shannon information. Some basics of quantum information.

*Phase transitions.* Ising model. Lattice gas. Symmetry breaking. Mean-field theory. First order vs. second order phase transitions. Order parameters. Correlation Length. Landau theory.

*Monte Carlo methods.* Practical methods for Monte Carlo simulations with Boltzmann sampling. Connection to Quantum Monte Carlo methods for electronic structure.

*Classical Statistical Mechanics and its Application to Liquids.* Phase space. Classical expressions for the partition function. Maxwell distribution of velocities. Pair correlation functions, radial distribution functions $g(r)$, and their measurement via scattering/diffraction. Thermodynamic properties from $g(r)$. Reversible work theorem.

*Kinetics and non-equilibrium processes.* Onsager's regression hypothesis and time-correlation functions. The fluctuation-dissipation theorem. Response functions. Transition-state theory for reaction rates. Friction and the Langevin equation. Brownian motion.

**Student Accessibility and Support Center (SASC):** If you have a physical, psychological, medical, or learning disability that may impact your course work, please contact the Student Accessibility Support Center, 128 ECC Building, (631) 632-6748, or at sasc@stonybrook.edu. They will determine with you what accommodations are necessary and appropriate. All information and documentation is confidential. Students who require assistance during emergency evacuation are encouraged to discuss their needs with their professors and SASC. For procedures and information go to the following website: https://ehs.stonybrook.edu/programs/fire-safety/emergency-evacuation/evacuation-guide-people-physical-disabilities

**Academic Integrity:** Each student must pursue his or her academic goals honestly and be personally accountable for all submitted work. Representing another person's work as your own is always wrong. Faculty are required to report any suspected instance of academic dishonesty to the Academic Judiciary. For more comprehensive information on academic integrity, including categories of academic dishonesty, please refer to the academic judiciary website at https://www.stonybrook.edu/commcms/academic_integrity/

**Critical Incident Management**: Critical Incident Management: Stony Brook University expects students to respect the rights, privileges, and property of other people. Faculty are required to report to the Office of Student Conduct and Community Standards any disruptive behavior that interrupts their ability to teach, compromises the safety of the learning environment, or inhibits students' ability to learn. Until/unless the latest COVID guidance is explicitly amended by SBU, during Spring 2022 "disruptive behavior" will likely include refusal to wear a mask during classes.
For the latest COVID guidance, please refer to: https://www.stonybrook.edu/commcms/strongertogether/latest.php

**Electronic Communication** Email to your University email account is an important way of communicating with you for this course. For most students the email address is firstname.lastname@stonybrook.edu, and the account can be accessed here: http://www.stonybrook.edu/mycloud. *It is your responsibility to read your email received at this account.* For instructions about how to verify your University email address see this: http://it.stonybrook.edu/help/kb/checking-or-changing-your-mail-forwarding-address-in-the-epo .

**Religious Observances:** See the policy statement regarding religious holidays at

http://www.stonybrook.edu/commcms/provost/resources/rel.html

Students are expected to notify the course professor by email of their intention to take time out for religious observance. This should be done as soon as possible but definitely before the end of the add/drop period. At that time they can discuss with the instructor(s) how they will be able to make up the work covered.