PHYS 617 Course Outline
Instructor: Steve Pressé

Why Stat Mech?:
This is a graduate course in equilibrium statistical mechanics. The purpose of statistical mechanics is to draw inferences about equilibrium probability distributions of systems composed of many (often interacting) degrees of freedom. Statistical mechanics is the foundation of biophysics, condensed matter physics and much of physical chemistry and quantitative biology. As we will discuss, the tools of statistical mechanics are broadly applicable across the sciences.

Outline:
We will first review thermodynamics as well as aspects of probability theory and asymptotic methods relevant to systems composed of many random variables. We will then frame statistical physics as a probabilistic inference problem. In this light, we will introduce the concept of maximum entropy and arrive at ensemble theory. We will then discuss key results from both classical and quantum statistical mechanics. An introduction to critical phenomena and the renormalization group will also be presented if time allows. We will put an emphasis on presenting this material in the modern language of statistical inference relevant to applied mathematics and biology rather than to introduce this material from the more traditional perspective of kinetic theory of gases and ergodic theory.

I am not in physics, should I take this?:
The quantum and classical mechanics presented will largely be self-contained. If you are from outside of physics and are considering this course, please come talk to me – this course as presented is relevant to disciplines outside of physics including physical chemistry, quantitative biology and certain branches of applied math and engineering.

Our Goals:
The purpose of this course is two-fold. First, this course should help students transition into research and navigate the literature. Second, it should provide students with a basic understanding –and an appreciation for– statistical modeling in the physical and biological sciences.

Grades:
Students may form study groups to work on problem sets which will be assigned approximately every week. However, all students must write-up their own solutions. Problem sets are due at 4pm on the due date; late problem sets are **not** accepted. All solutions will be posted online. An exam can be skipped or made up if an excuse for an **extenuating circumstance** can be substantiated. In this case, a doctor's note or a letter from the physics department chair are required. 60 is the passing grade. Active class participation is required. To get full grades in class participation, students are expected to attend all classes and routinely ask questions. (10% Class participation, 30% 2 Midterms, 30% Problem Sets, 30% Final).

Studying for Tests/Exams:
The best way to study is to have completed and understood 1) all of the assigned questions in the problem sets and 2) the relevant problems in the chapters covered in the required text (for which solutions are provided in the text).

Required text:
1) M. Kardar, Statistical Physics of Particles

Helpful text:
2) G. Casella and R. Berger, Statistical Inference

More physics references:
1) M. Kardar, Statistical Physics of Fields
2) R.K. Pathria, Statistical Mechanics
3) J. M Yeomans, Statistical Mechanics of Phase Transitions
4) P. Nelson, Biological Physics

More math references:
1) C.M. Bender and S.A. Orszag, Advanced Mathematical Methods for Scientists and Engineers
2) P. Lee, Introduction to Bayesian Statistics
3) E.T. Copson, Asymptotic Expansions

Class Schedule

Week 1 (Aug 19th - Aug 23rd):
Lecture I (Thermodynamics) and II (Second law) –Nothing due.

Week 2 (Aug 26th - Aug 30th):
Lecture III (Thermodynamic potentials) and IV (Stability conditions) –PSET 1 due.

Week 3 (Sep 2nd - Sep 6th):
Lecture V (Laws of probability) and VI (Likelihood functions) –PSET 2 due.

Week 4 (Sep 9th - Sep 13th):
Lecture VII (Bayesian methods and priors) and VIII (Characteristic functions and central limit theorem) –PSET 3 due.

Week 5 (Sep 16th - Sep 20th):
Lecture IX (Information theory) and X (Shore and Johnson axioms) –PSET 4 due.

Week 6 (Sep 23rd - Sep 27th):
Lecture XI (MaxEnt and relation to Bayes' theorem) and XII (Image reconstruction) –PSET 5 due.

Week 7 (Sep 30th - Oct 4th):
Lecture XIII (Path entropies) and Midterm I –Nothing due.

Week 8 (Oct 7th - Oct 11th):
Lecture XIV (Microcanonical ensemble) and XV (Mixing entropy and canonical ensemble) –PSET 6 due.

Week 9 (Oct 14th - Oct 18th):
Lecture XVI (Other ensembles) and XVII (Interacting systems and cumulant expansions) –PSET 7 due.

Week 10 (Oct 21st - Oct 25th):
Lecture XVIII (Cluster expansion) and XIX (Virial coefficients and van der Waals) –PSET 8 due.

Week 11 (Oct 28th - Nov 1st):
Lecture XX (Variational methods) and XXI (Condensation and critical phenomena) –PSET 9 due.

Week 12 (Nov 4th - Nov 8th):
Lecture XXII (Intro to quantum statistical mechanics) and Midterm II –Nothing due.

Week 13 (Nov 11th - Nov 15th):
Lecture XXIII (Quantum micro and macrostates) and XXIV (Hilbert spaces) –PSET 10 due.

Week 14 (Nov 18th - Nov 22nd):
Lecture XXV (Quantum canonical formulation) and XXVI (Degenerate Fermi gases) –PSET 11 due.

Week 15 (Nov 25th - Nov 29th):
Lecture XXVII (Degenerate Bose gas) and Thanksgiving Holiday– Nothing due.

Week 16 (Dec 2nd - Dec 5th):
Lecture XXVIII (He4) and No Lecture –PSET 12 due.

Week 17 (Dec 10th - Dec 13th):
Final Exam.