Advanced Statistical Physics

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Objectives of the course:

This is a fast paced class, tailored to a wide audience of second year (and higher), experimental and theoretical physics and astrophysics students. The main objective of the class is to give a broad perspective of advanced statistical physics concepts: non-equilibrium, classical and quantum and phase transitions, with direct applications across different areas with the focus on interdisciplinary applications.

Non-equilibrium I: Classical

Brownian motion: ballistic vs. diffusion, mean free path and relaxation time. Langevin equation: fluctuation and dissipation, application: the Drude conductivity in metals. The Fokker-Planck equation. **Macroscopic approach** to transport phenomena: kinetic theory. Fick's law, diffusion, thermal conductivity, viscosity. **Macroscopic approach** to fluid dynamics: continuity and Euler equations. **Microscopic approach**: the Boltzmann equation: collisions and scattering cross sections, mean free path and relaxation time, the relaxation time approximation and approach to equilibrium. H-theorem and entropy. Local Thermodynamic Equilibrium (LTE) Transport phenomena: Drude conductivity, Fick's law derivation and diffusion, thermal conductivity. Hydrodynamics: collisional invariants and conservation laws: the laws of Hydrodynamics. Zeroth order: ideal fluids: sound waves and conservation of vorticity. First order: viscous Hydrodynamics with transport: damped sound waves and hydrodynamic modes. Navier-Stokes equation: Reynolds number. Some concepts on turbulence: energy cascades and Kolmogorov spectrum.

Non-Equilibrium II: Quantum

Brief summary of second quantization. Quantum Brownian motion and quantum fluctuation-dissipation. Two level systems and radiation: spontaneous and stimulated emission, detailed balance and blackbody radiation. The quantum Boltzmann equation: Pauli blocking and Bose-enhancement. Relaxation time approximation. Time evolution of a density matrix: quantum master equation and Lindblad form: dissipation. An explicit example: particle-bath models. Approach to thermalization.

Phase transitions and critical phenomena:

Experimental observations: Van-der Walls EOS and liquid gas phase transition. The Ising ferromagnet, mean-field theory. Spontaneous and explicit symmetry breaking.

Correlation function and correlation length. Susceptibilities: Curie's law. Discrete symmetries: domain walls, continuous symmetries: Goldstone modes. Landau Ginzburg theory, classification. Second order phase transitions: scaling hypothesis and critical exponents, fluctuations. Ideas on the renormalization group. First order phase transitions: metastable states and nucleation, critical droplets, latent heat and Clausius-Clapeyron equation. Tricritical phenomena. Dynamics: time-dependent Landau Ginzburg: critical slowing down, instability towards phase separation: spinodal decomposition and domain formation.

Prerequisites: Statistical Physics I, Electrodynamics and Quantum Mechanics I and II.

Suggested books: Equilibrium and Non-Equilibrium Statistical Thermodynamics by M. Lebellac, F. Mortessagne, G. G. Batrouni (I will use this book as a ``roadmap''), also some of the material is covered by: Statistical Mechanics by Pathria, Statistical Physics by K. Huang, Thermal and Statistical Physics by Reif. I will draw material from all of these books.

I will share my class notes as PDF files with all enrolled students, the notes will be sent via e-mail at least two days in advance of each class.

Homework and Essays: There will be bi-weekly (or tri-weekly) homework set (4-5 problems) and one final Essay.

Grades: (1/2)x(average homework)+(1/2)x(Essay)

Office Hours: Upon request and appointment, either in person or virtual via Zoom just send me an email with a request and time availability and we will find a time of mutual convenience. I will also respond to questions via e-mail within 24 hours (at most!).