Welcome to the class! "Non-equilibrium statistical physics"

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This course is designed to introduce some of the concepts employed in the study of macroscopic systems away from their state of thermodynamic equilibrium, including linear response, fluctuation-dissipation theorem, diffusion in various contexts (from first passage to chemical reactions), work-energy theorems, active and driven systems.

Unlike equilibrium statistical physics, with its high level of generality and universality, the non-equilibrium statistical physics is essentially a set of many examples, or the art of solving the macroscopic physics problems. Accordingly, the main emphasis in the course will be on problem solving. Many examples will be taken from the fields of soft condensed matter of both biological and non-biological origin. Connections with other branches of physics will be emphasized.

MAJOR TOPICS TO BE INCLUDED:

1. Linear response (Onsager reciprocity, diffusion equation and its generalizations, Smoluchowski equation);
2. Fluctuation dissipation theorem;
3. First passage problems;
4. Kramers theory and rate of barrier crossing;
5. Non-equilibrium statistical mechanics (work-energy theorems, commitment and reaction coordinate, transition path sampling);
6. Motors and ratchets;
7. Hydrodynamic coupling, electrophoresis and electroosmosis,
8. Kinetics of phase transitions, nucleation, spinodal decomposition.

This is an "ideal world" plan. In reality, because of time constraints, some of the topics will be only mentioned, while others will be developed to some depth.

MAJOR TOPICS NOT INCLUDED

Boltzmann equation, kinetic theory of gases, and its many uses in solid state physics (where "gas" consists of quasi-particles).

PRE-REQUISITES

The class is designed for advanced graduate students. Although no sophisticated mathematics will be used, the sufficiently mature understanding across major physics disciplines is expected. Good working knowledge of equilibrium statistical mechanics is a must. No programming virtuosity is required, but simple computations are expected.

BOOKS AND OTHER SOURCES

There is no book which can serve as a single text for the class. Useful sources include, but are not limited to, the books [1–7].

Additional reading from current journals will be assigned during the semester.

CONSTANTS AND UNITS

In this class, $c = \infty$ (nothing relativistic), $\hbar = 0$ (although quantum mechanical analogies are actively used), $k_B = 1$, Avogadro's number N_A is not in use, i.e., concentration is defined as the number of molecules (not moles!) per unit volume, $\nabla \cdot \mathbf{E} = 4\pi\rho$ (i.e., no ϵ_0), magnetic susceptibility of vacuum μ_0 is also not in use.

In many (but not in all) cases, $2 \sim \pi \sim 2\pi \sim 1$.

HOME WORKS

The VERY IMPORTANT part of the course will be problem solving in every week home works. The solutions of some (not all!) home works will be handed out, they will be considered as a hand-out material and students will be expected to study them carefully, like a text.

In general, a significant amount of reading and thinking will be expected to succeed in class.

PAPERS

Before November 1, students can discuss with the instructor the possibility to prepare a paper (not necessarily publishable) on a specific research topic. Arrangements for papers are not considered at the end of the semester (i.e., after November 1).

GRADING

Grading will be mostly based on the home works. Every homework assignment will include about 5 or so problems. Every problem will be graded on the scale from 0 to 3 (0,1,2,3). That means, $3n_j$ is the maximal grade for the home work j with n_j problems; if you receive ξ_{ij} for problem i in home work j, where $i = 1, 2, \ldots, n$, then percentage will be computed as $x_j = \sum_{i=1}^{n} \xi_{ij}/3n_j$, and this will be done for every homework assignment. Homeworks will be due one week after they are handed out (i.e., placed on the web). No late homeworks will be accepted. Up to three homeworks can be dropped in case of an illness or another important circumstances (like religious observances, family emergencies, etc). There will be one mid-term test and the final exam. The dates for both tests will be adjusted later. Mid term test will be given in regular class time. The 3-hours final exam will be scheduled for one of the days of the finals week. Tests and exams will be graded by the same scheme as homeworks. Papers will be graded based on their volume, quality, and presentation; on the instruction's discretion, paper can cost anywhere between nothing and up to three completed homeworks. Final overall percentage, x, will be chosen as the better of the two:

- average of all HW's percentages x_j except the dropped ones (65%), midterm (10%) and final (another 25%).
- average of all HW's percentages x_j (75%) except the dropped ones, and the final exam (another 25%).

Final letter grade will be determined based on the percentage using the following formula: A if $x \geq 0.85$; $A-$ if $0.85 > x \geq 0.8$; $B+$ if $0.8 > x \geq 0.75$; B if $0.75 > x \geq 0.7$; $B-$ if $0.7 > x \geq 0.65$; $C+$ if $0.65 > x \geq 0.55$; C if $0.55 > x \geq 0.5$; $C-$ if $0.5 > x \geq 0.45$; Anything below 0.45 is not a passing grade. There will be no "curve".

[1] P. M. Chaikin and T. C. Lubensky, *Principles of condensed matter physics* (Cambridge University Press, 1995).
[2] L. D. Landau and E. M. Lifshitz, *Statistical Physics, Part 1 (Course of Theoretical Physics, Volume 5)* (Butterworth-Heinemann; 3 edition, 1980).
[3] M. Doi, *Soft Matter Physics* (Oxford University Press, 2013).
[4] N. van Kampen, *Stochastic Processes in Physics and Chemistry* (Elsevier, 2007).
[5] E. M. Lifshitz and L. Pitaevskii, *Physical Kinetics (Course of Theoretical Physics, Volume 10)* (Butterworth-Heinemann, 2002).
[6] D. Chandler, *Introduction to Modern Statistical Mechanics* (Oxford University Press, 1987).
[7] E. M. Lifshitz and L. P. Pitaevskii, *Statistical Physics, Part 2: Theory of the Condensed State (Course of Theoretical Physics, Volume 9)* (Butterworth-Heinemann, 2002).