TENTATIVE PY 896 COURSE OUTLINE: FUNDAMENTAL KINETIC PROCESSES

Preface:

While equilibrium statistical physics is well-developed, the statistical description of non-equilibrium systems is still not mature. In spite of much effort, an over-arching formalism, such as the Boltzmann factor or the partition function, does not yet exist in non-equilibrium phenomena. Because of this disconnect between fundamentals and applications, the approach of this course is to present paradigmatic yet pedagogical examples as a user-friendly way to gain general insights. I will attempt to make this course as self-contained and accessible as possible, so that an interested student can appreciate the main results by carefully working through the lecture notes. While PY 541 and 542 would provide helpful background, a motivated graduate student should be able to enjoy this course without these background classes.

A major main focus of the course will be on the fundamental kinetic processes of aggregation, fragmentation, and adsorption. Aggregation is the process by which two clusters irreversibly combine in a mass-conserving manner to form a larger cluster. This classic process nicely demonstrates the role of conservation laws, the utility of exact solutions, the emergence of scaling in cluster-size distributions, and the power of heuristic derivations. Fragmentation is the complementary process in which an object undergoes repeated breakup into smaller fragments. This phenomenon again illustrates the utility of exact and scaling solutions. Finally, in irreversible adsorption, the kinetic approach provides a simple understanding of the final density of absorbed particles, a quantity that is difficult to obtain by direct means.

Another major portion of the course will be devoted to the time evolution of systems that involve the competition between multiple phases. Examples will include classical spin systems, such as the kinetic Ising model and the voter model. The kinetic Ising model occupies a central role in statistical physics because of its broad applicability to spin systems and many other dynamic critical phenomena. While the voter model is not as well known, it is even simpler and is exactly soluble in all dimensions. We will then discuss a number fundamental examples associated with kinetic phenomena in phase ordering problems.

If there is time, I will discuss the structure of growing networks and collision-driven phenomena. For the former, I plan to present the master equation to determine the degree distribution of growing networks and other fundamental geometrical features. For the latter, I'll present the Boltzmann equation in the context of explicitly soluble examples. These include traffic models, and aggregation and annihilation processes in which particles move at constant velocity between collisions.

Basic Course Information:

The text for the course is based on a book that I am currently writing in collaboration with Eli Ben-Naim and Paul Krapivsky. Relevant sections of the book will be posted on the course website: physics.bu.edu/∼redner/896.html periodically during the semester.

As befits an advanced graduate course, the grading requirements will be informal and the details will be announced at the first lecture.

Tentative Course Outline

1. DIFFUSION

- A Fundamentals of Random Walks
  - The probability distribution; central limit theorem; transience and recurrence
- B The Diffusion Equation
  - Basic solution methods; first-passage processes; connection with electrostatics

2. BASIC TOOLS

- A Langevin Equation
- B Fokker-Planck Equation
- C Master Equation

3. AGGREGATION

- A Theory of the Reaction Rate
- B Exact Solutions: reaction rates $K_{ij} = 1$, $K_{ij} = ij$, $K_{ij} = i + j$.
- C Scaling Theory
- D Extensions: aggregation with input, exchange processes, finite systems

4. FRAGMENTATION

- A Examples of Exact Solutions
  - constant & linear breakup rate, shattering transition
- B Scaling theory
- C Applications: steady material input & geometrical fragmentation.

5. ADSORPTION

- A Dimer Adsorption in One Dimension: jamming and final coverage
- B Adsorption of Sticks on a One-Dimensional Line
- C Adsorption-Desorption Processes

6. KINETICS OF SPIN SYSTEMS

- A Ising Spin Systems with Glauber Dynamics
  - exact results in one dimension, domain size distribution
- B Ising Spin Systems with Kawasaki Dynamics
- C Disordered Systems
- D Voter Model
- E Domain Evolution Processes

7. PHASE ORDERING KINETICS

- A Kolmogorov-Avrami Model
- B Landau Ginzburg Equation/Curvature-Driven Growth
- C Lifshitz-Slyozov Theory

8. GROWING NETWORKS

- A The Basic Models
- B Master Equation and Degree Distribution
- C Structural Properties

9. COLLISION PROCESSES

- A The Maxwell-Boltzmann Distribution
- B Boltzmann Transport Equation
- C Lorentz Gas
- D Inelastic Collisions
- E Traffic Models
- F Annihilation