__2020 Fall Advanced Course in Materials Science__

MSE 676 Soft Matter Physics

Instructor: Prof. T. Egami

Time: Wed. 2:15 – 4:55

Instruction: F2F, location to be determined.

Textbook: T. Egami, *Fascination with Dynamic Aperiodic Matter: Physics of Liquids and Glasses*, to be published from Cambridge University Press. In addition, relevant reviews and papers will be electronically sent.

Outline:
Soft-matters, including liquids, colloids, gels, rubbers, polymers, macro-molecules and biological matter, are more complex and diverse in chemistry and structure, compared to the conventional hard-matters. They are usually more mechanically flexible, hence the name, "soft-matter", was chosen. However, softness is relative, and can easily be dealt with by readjusting the energy scale. What is fundamentally different from hard-matter is that they are dynamic and do not have a periodic lattice structure. So, I prefer the name, "dynamic aperiodic matter (DAM)". The conventional theories in condensed-matter-physics assume lattice periodicity fixed in space and time. Consequently, these theories are largely powerless for soft matter. What we need is a new basic science for DAM, which is the focus of this course. We discuss experimental methods to characterize dynamics and structure, from macroscopic to atomic scales in space and time, theoretical framework to elucidate the dynamics, new concepts for atomic transport, and approach to applications. This course is designed for a wide spectrum of graduate students interested in the basic aspects in soft matter science, in physics, chemistry, materials science, chemical and other engineering, and it does not require high levels of knowledge in theoretical physics. Only strong curiosity in new subdomain of science is required.

1. Introduction

General properties of various groups of condensed-matter, timescale of dynamics, hard vs. soft, liquids vs. solids, glass vs. crystal, crystallization, glass transition, atomic, electronic, and thermal transport, amorphous and organic semiconductors, soft-matter-like behavior of hard-matter, and various applications.

2. Macroscopic dynamics

Elasticity, anelasticity, Debye model of relaxation, mechanical and dielectric relaxation, diffusion, viscosity, thermal and electrical conductivity.

3. Microscopic dynamics

Phonons in crystal, glass, and liquid, random walk diffusion, caging, boson peak, non-phonon excitation, topological excitations.

4. Structure

Dense random packing, random network structure, pair-density function (PDF), coordination number, determination of PDF by diffraction experiments, short- range-order (SRO) and medium-range-order (MRO), first-sharp-diffraction-peak, the Van Hove function.

5. Measurement of microscopic dynamics

Inelastic x-ray and neutron scattering, quasi-elastic neutron scattering, neutron spin echo, Raman scattering, NMR.

6. Computer simulation of structure and properties

Molecular dynamics and Monte-Carlo simulation of atomic transport, the glass transition and relaxation.

7. Theories of strongly disordered systems

Concept of percolation, frustration, localization, configurational entropy, concept of dynamic correlation, statistical mechanics of dynamic disorder, fluctuation-dissipation theorem, concept of potential energy landscapes.

8. Topological fluctuation theory

Fluctuations in atom connectivity network, atomic-level stresses, the glass transition, liquid fragility and MRO, glass formability, mechanical deformation.

9. Water and aqueous solution

Two states of water, dielectric relaxation, hydrogen bond, ice rule, protons in ice, aqueous solution, water-like behavior of other liquids.

10. Colloids

Boltzmann theory, mode-coupling theory, shear thinning.

11. Polymers

Structure, β-relaxation, reptation, crazing, organic metal and semiconductor.

*Grades will be based on class discussions, three projects and one term paper.

Students are required to wear face masks at all times and maintain social distancing (6 feet between individuals in traditional classrooms. Students who are feeling ill or experiencing symptoms such as sneezing, coughing, or a higher than normal temperature will be excused from class and should stay at home. Instructors have the right to ask those who are not complying with these requirements to leave class in the interest of everyone's health and safety. Additionally, following other simple practices will promote good health in and out of the classroom, such as frequent and thorough hand washing, wiping down desks and seats with disinfectant wipes whenever possible, not sharing personal items such as pens and cell phones, and avoiding crowded hallways and other enclosed spaces.