2016 Fall Advanced Course in Materials Physics

MSE 676 Physics of Liquids and Glasses (Advanced Topic in Materials Science)

Instructor: Prof. T. Egami

Time: Wed. 2:15 – 4:55

Textbook: J.-L. Barrat and J.-P. Hansen, *Basic Concepts for Simple and Complex Liquids*, Cambridge University Press, 2003. In addition relevant reviews and papers will be electronically sent.

Outline:

Solid-state-physics, the former name of condensed-matter-physics, has been spectacularly successful and introduced the age of information technology. In comparison, liquids and glasses, and other strongly disordered systems such as colloids and polymers, are poorly understood at an atomistic level, even though they are important in many fields including physics, chemistry, materials science, chemical and mechanical engineering, biology and the medical sciences. The problem is that liquids and glasses are condensed matter with strong atomic correlations, unlike gasses. However, the conventional theories of condensed-matter-physics are built upon the assumption of crystal periodicity, and are powerless for liquids and glasses which do not have a periodic structure, because the deeply many-body nature of the atomic interactions frustrates conventional approaches. The purpose of this course is to introduce graduate students in physics, chemistry, materials science, chemical and other engineering to the general physical properties of strongly disordered systems, mainly liquids, glasses, colloids, polymers, spin-glasses and relaxor ferroelectrics, and to some theories currently available to describe them.

1. Introduction

General properties of liquids vs. solids, the glass transition, structural relaxation, tunneling states, strongly disordered crystals, metallic, covalent, ionic, molecular and polymeric glasses.

2. Structure

Dense random packing, random network structure, pair-density function (PDF), coordination number, determination of PDF by diffraction experiments, free-volume.

3. Physical properties

Viscosity and diffusion, electrical and thermal conductivity, magnetic properties, spin-glasses, mechanical properties.

4. Thermodynamics

Configurational entropy, Kauzmann paradox, Vogel-Fulcher relationship and WLF relaxation, liquid fragility, two-level systems, nucleation of crystals in supercooled liquids and glass formation.

5. Computer simulation of structure and properties

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

6. Theories of strongly disordered systems

Concept of percolation transition, frustration, Anderson localization, coherent potential approximation, Ziman theory of resistivity.

7. Theories of spin glasses

Mean-field theory, replica theory of Edwards and Anderson, irreversibility line.

8. Phenomenological theories of liquids and glasses

Free-volume theory, Adam-Gibbs theory, mode-coupling theory, concept of energy landscapes.

9. Topological fluctuation theory

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

10. Quantum Liquids

Superfluidity, Landau theory, quantum phenomena in glasses.

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

8/17	Introduction
8/24	Structure
8/31	Physical properties
9/7	Structure analysis (Dmowski)
9/14	Thermodynamics
9/21	Thermodynamics
9/28	Simulation
10/5	Theory
12	Theory
19	Spin glass
26	MS&T. Spin-echo and slow dynamics (Ohl)
11/3	Topological fluctuation theory
10	HEA. Mechanical deformation (Dmowski)
17	Quantum liquid
24	No class