PHY628 Physics of Soft Matter and Fluids

Instructor: Sivasurender Chandran

Course Description and Objectives: 3-1-0-0 (11 credits)

In our day-to-day life, we observe many forms of matter that are neither solid nor liquid. For example, foam, paste, gel, shaving cream, cake, liquid crystal display, pile of sand, paints and any biological cells. These wide variety of materials systems are composed of materials like colloids, polymers, micelles, liquid crystals, and emulsions. The mesoscopic (intermediate between molecular and macroscopic dimensions) length scales of these systems and the corresponding differences in the time and energy scales offer behaviour that are strikingly different from the conventional condensed matter. Understanding the behaviour of these systems, within a single framework, forms a vibrant discipline termed the soft condensed matter or in short, soft matter.

The aim of this course is to emphasize the generic features common to various soft materials and develop simple models accounting for their behaviour. We will begin with developing the necessary background on the continuum level description of solids and liquids, and the statistical aspects necessary for understanding the structure and dynamics at the microscopic level. Subsequently, we will demonstrate the applicability of these ideas in understanding the different phases of soft matter like colloids, polymers, and liquid crystals. If time permits, we will also discuss about statistical aspects of interface evolution and active and living matter. Throughout the course, we will emphasize how such understanding provides us avenues to delve into several interesting features of everyday life and of the intriguing biological systems.

Prerequisite: Statistical Mechanics (PHY412 or equivalent).

Course Grading:

The final grading will be based on your performance throughout the semester. This will be evaluated using the following distribution: Assignments – 10 %; Quizzes – 25 %; Mid-semester – 30 %; End-semester – 35 %.

Please be informed of the following:

- ✓ Attendance is not mandatory. However, following classroom teaching and the follow-up discussions will help you develop a systematic understanding of the content. So, all students are requested to attend all the classes.
- ✓ One assignment will be given for every sub-module, solving which will boost your understanding.
- ✓ We will have 4 – 5 quizzes. All quizzes will be surprise quizzes.
- ✓ Irrespective of the performance in assignments and quizzes, attendance in Mid-Sem and End-Sem are mandatory.
- ✓ Grades will be awarded on a relative basis.
- ✓ Professional ethics will be given significant importance. If you are found cheating during quizzes and exams you will be awarded an **F** grade.

Contents:

1. ***Introduction – The challenges, relevance and fun of soft matter:*** Inspiration via examples of the broad class of soft matter systems; Length, time and energy scales; Universal properties; Our approach of the course.
2. ***Groundwork:***
   a. ***Continuum Approach:***
      i. ***Fluid Dynamics*:** Continuum description of fluids – material derivative, conservation of mass, energy and momentum; Navier-Stokes equations, different flow regimes and the relevance of Reynold's number; Contact angle and wetting
      ii. ***Elasticity:*** Strain tensor, linear stress-strain relation, Poisson ratio; Brief discussion on elastodynamics; Bending and buckling of rods and sheets; Elastic response of particles jammed together
   b. ***Microscopic approach***: Radial distribution function and structure factor (spatial and temporal); Relation between radial distribution function and thermodynamic variables; Langevin equation of Brownian motion; Fokker Planck equation for the probability distribution.
3. ***Phases of Soft Matter***:
   a. ***Colloids***: Different interactions – Van der Waals, Depletion, and electrostatic interactions; Hard spheres as model systems – entropic interactions, entropy induced crystallization, and glass formation; rheological behaviour of colloids.
   b. ***Polymers***: Ideal chains excluded volume effects, and the Flory argument; Worm like chain for biopolymers; Polymers in Solution – Flory-Huggin's theory; Rouse, reptation and Zimm models of polymers; Rheological behaviour of polymers.
   c. ***Liquid Crystals***: Phases of liquid crystals; Order parameter, Landau-de Gennes theory for isotropic to nematic transition; Frank energy expression for nematic director field; Topological defects in the director orientation and their relevance in biological systems*.
   d. ***Interfaces and Surfaces****: Fluid Interfaces; Deposition of particles as a simple idea to develop interfaces; Edward-Wilkison and Kardar–Parisi–Zhang models at a phenomenological level.
   e. ***Active and Living Matter****: Examples of active systems – bacterial suspensions, Janus particles; Flocking – Vicsek Model; Motility induced phase separation.

** Will be discussed only if time allows*

Reference books:

1. *Soft Matter: Concepts, Phenomena and Applications*, Wim van Sarloos, Vincenzo Vitelli, and Zorana Zeravcic, Princeton University Press (Princeton and Oxford) 2024
2. *The Restless Cell – Continuum Theories of Living Matter*, Christina Hueschen, and Rob Phillips, Princeton University Press (Princeton and Oxford) 2024
3. *Essentials of Soft Matter Science*, F. Brochard-Wyart, P. Nassoy, P-H. Puech (CRC Press, 2019)
4. *Soft Matter Physics*, Masao Doi (Oxford University Press, 2013)

Additional references will be provided during the lectures