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. Examples include, foam, paste, gel, shaving cream, cake, liquid crystal display, granular materials such as sand, paints, and even biological cells. Despite their diversity, these materials systems are composed of common building blocks such as colloids, polymers, micelles, liquid crystals, and emulsions. What distinguishes these materials is the presence of mesoscopic length scales (intermediate between molecular and macroscopic dimensions) and the resultant slow dynamics and weak interactions. This, in turn, gives rise to behaviours that are strikingly different from the conventional condensed matter. Understanding such systems within a unified framework forms the basis of a vibrant field known as the soft condensed matter or simply, soft matter.

The aim of this course is to identify the generic principles common to a wide range of soft materials and to develop simple, physically transparent models to describe their behaviour. We will begin by introducing the essential background in continuum description of solids and fluids, along with the statistical framework required to understand structure and dynamics at the microscopic level. Building on these ideas, we will explore major classes of soft matter systems like colloids, polymers, and liquid crystals. If time permits, we will also discuss the statistical physics of evolving interfaces, as well as active and living matter. Throughout the course, emphasis will be placed on connecting fundamental concepts to observable phenomena, ranging from everyday materials to complex biological systems.

Prerequisite: Thermodynamics and equilibrium statistical mechanics.

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 – 15%; Mid-semester – 20 %; Project/Paper-presentation (group of 2 – 4) – 25 %; End-semester – 30 %.

Course policies and guidelines:

- ✓ Attendance is not mandatory. However, regular participation in classes and follow up discussions is strongly encouraged, as it will help you develop a systematic understanding of the material.
- ✓ One assignment will be given approximately every fortnight. Students are encouraged to discuss and work together in understanding problems; however, each student must submit their own solutions independently.
- ✓ There will be several quizzes in the semester and all of them will be unannounced.
- ✓ Attendance in mid semester and end semester examinations is mandatory.
- ✓ Grades will be awarded on a relative basis.
- ✓ Professional ethics are of utmost importance. Any form of academic dishonesty, including cheating during quizzes, or examinations, will result in an **F** grade.

Contents [This will not be the teaching sequence]:

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. ***Essential Mathematics:***
        i. Tensor calculus, Fourier and Laplace transform
    b. ***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
    c. ***Microscopic approach***:
        i. ***Structure***: Radial distribution function and structure factor (spatial and temporal); Relation between radial distribution function and thermodynamic variables.
        ii. ***Dynamics***: 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)

<u>*Additional references will be provided during the lectures*</u>