

1 Introduction

AKA Soft Condensed Matter Physics (MC mai ghoom phir ke CMP pe aa gya).
Course content

1. Intro to soft matter
2. Viscoelasticity
3. Colloids
4. Polymers
5. Surfactants
6. Liquid Crystals

Books

- Soft Matter Physics (Richard Jones)
- Soft Matter Physics (Masao Doi)
- Introduction to the Theory of Soft Matter (Jonathan Selinger) [liquid crystals]

So, there's three adjectives in front of the word 'Physics'.

1.1 Matter

Composed of atoms or molecules. Matter refers to collections of atoms and molecules. Don't go about referring to a single atom as 'matter'.

It is expected that when we say 'matter', we have a very large ($\approx N_A$) number of building components.

So, how does one go about dealing with such systems? Statistical physics. Your Hamiltonian formalism and Newton's equations will shit the bed.

Solid systems and gaseous systems are easy to deal with for Physicists, because some really neat approximations can be made. In liquids, however potential energy \approx kinetic energy.

[Missed some part of the lecture]

An example of Helium's phase diagram was given. There is a critical pressure below which it cannot exist in the liquid state. Point was $P > 0$ for the existence of liquid, or something like that. You need pressure for the existence of liquids.

You see, the world is not just made up of solid, liquid and gas only. Like what the fuck even is the phase of toothpaste and shampoo??

- Solid
 - Translational order
 - translationally broken symmetry
 - broken rotational symmetry
- Fluid
 - Translationally disordered

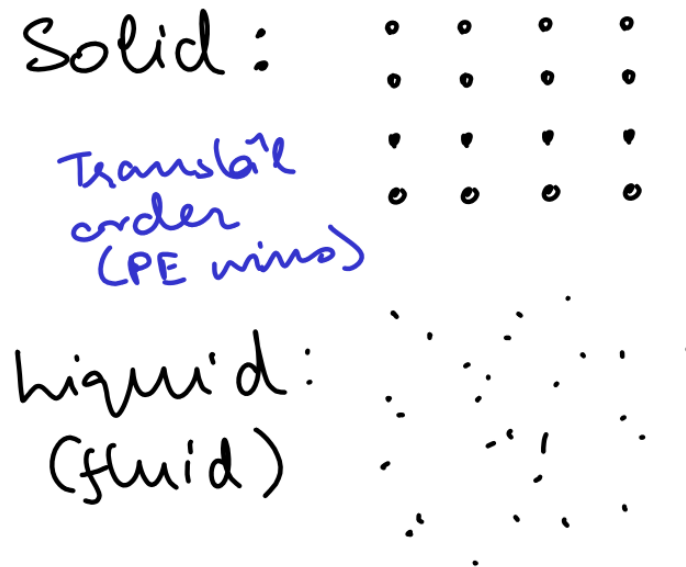


Figure 1: Fluids vs solids - order

- translationally symmetric
- rotational symmetries preserved

Deformations are not energetically favourable in solids and hence any attempts to move particles by shearing, compressing etc will result in strong restoring forces.

Fluids on the other hand have 0 elastic moduli

Then we have soft matter systems, where the elastic moduli are somewhere in between the above two cases.

Systems like liquid crystals are again quite unique because

- Rotational order
- No translational order

BTW time scales matter. Phase diagrams don't show time, only thermodynamic parameters. But, we generally think of different phases like solids, liquids etc in terms of their response functions - their dynamics. If something is hard, it's solid. If something flows, it's liquid. Phase diagrams do not really capture the dynamics properly.

1.2 Grading

- Home assignments - 33%
- Midsem - 33%
- Endsem - 33%

Intermolecular Forces

Must be attractive at some ranges (else cannot have condensed phases), corresponding potential should achieve minima somewhere.

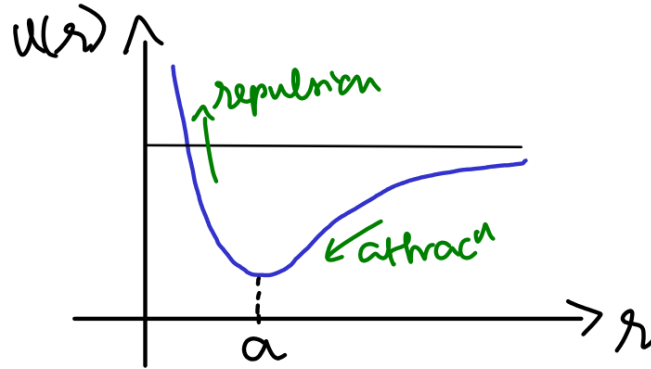


Figure 2: Typical interatomic potentials in condensed matter systems

$$\begin{aligned} r \rightarrow \infty &\implies -\frac{dU}{dr} = 0 \\ r \geq a &\implies -\frac{dU}{dr} \leq 0 \\ r < a &\implies -\frac{dU}{dr} > 0 \end{aligned} \tag{1}$$

Metallic Bond

A simple minded picture - positive cores form a lattice and negative carriers dispersed throughout the material. Coulomb forces responsible for holding the metallic bulk together.

Typical strength $\approx 10^{-18}$ J ≈ 6 eV, around 300 Kelvin.

Ionic Bonds

Similar bond energy as metallic bonds, bulk formed by interpenetrating lattices of positive and negative charge cores.

Covalent Bonds

Electron sharing and all that jazz. Typically weaker than ionic bonds

Van der Waals interactions

Initiated by spontaneous polarization of a molecule, which then polarizes nearby molecules and the overall medium can be modelled using some empirical potentials that simulate this interaction.

This is typically the weakest interaction, $k_B T \approx$ room temp. $U \sim \frac{1}{r^6}$

Hydrogen Bonds

O, F, N et cetera participate in Hydrogen bonding. refer to CBSE book nothing new here really.

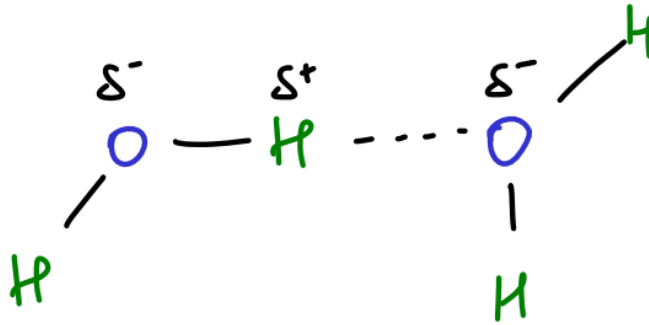


Figure 3: Hydrogen bonding in water

This gives rise to non-trivial properties, like the density of ice being lesser than the density of water. Bond strength $\sim 20 - 100 k_B$

What is ‘soft’ matter

We generally think of colloids, liquid crystals etc. The basic building units are mesoscopic in size (somewhere between micro and macro).

Where an atom is typically of the order of a few angstroms, soft matter building blocks are somewhere from a few nanometers to microns.

Consider the act of compressing some bulk material. We define the bulk modulus of the medium as

$$\kappa = \frac{\Delta P}{\Delta V/V} \quad (2)$$

Bulk moduli for condensed matter are very high, because the structure of the bulk material is maintained by the interatomic forces, which typically have a very narrow minimum range. Compressing those solids requires one to reduce the average interatomic distances, thus increasing the restoring force highly repulsive.

Similarly, we could also shear a bulk material. Shear modulus

$$G = \sigma \frac{L}{l} \quad (3)$$

where $\sigma = F/A$ is the shear stress and $\gamma = l/L$ or $\Delta L/L$ is the shear strain (see figure 5)

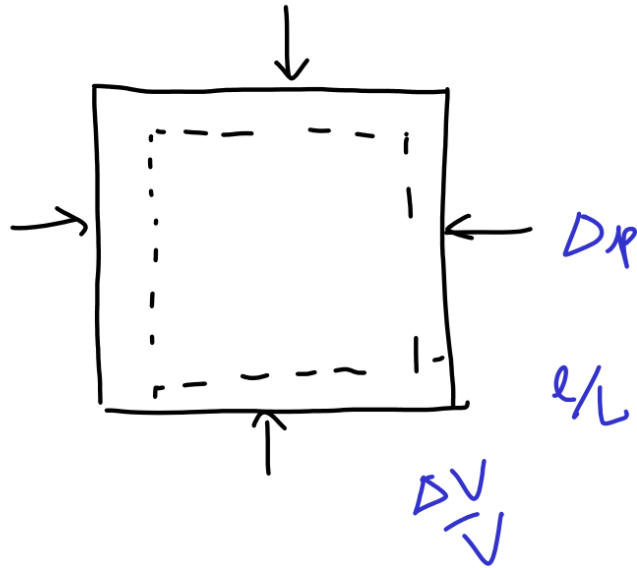


Figure 4: Doing a bulk compression

Why do soft materials have low G ?

Consider the toy model in figure 6 made using springs.

If we try to deform it, then we have

$$\begin{aligned}
 F &= k(r - a) \\
 \text{Stress, } \sigma &= \frac{F}{A} = \frac{k(r - a)}{a^2} \\
 \text{Strain, } \gamma &= \frac{r - a}{a} \\
 \text{Young's modulus, } Y &= \frac{\sigma}{\gamma} = \frac{k(r - a)}{a^2(r - a)} \cdot a = \frac{k}{a}
 \end{aligned} \tag{4}$$

During deformation that doesn't straight up destroy the whole bulk material, we are essentially moving in a small window around the potential minimum (see fig 2), we can Taylor expand the potential to get some harmonic dynamics.

$$U(r) = U(a) - \frac{1}{2!} \frac{d^2U}{dr^2} (r - a)^2 \tag{5}$$

Some important properties of soft matter systems

1. Disordered matter: energy scales $\approx k_B T$, e.g. granular matter
2. ???
3. ???
4. Thermal and entropic matter:

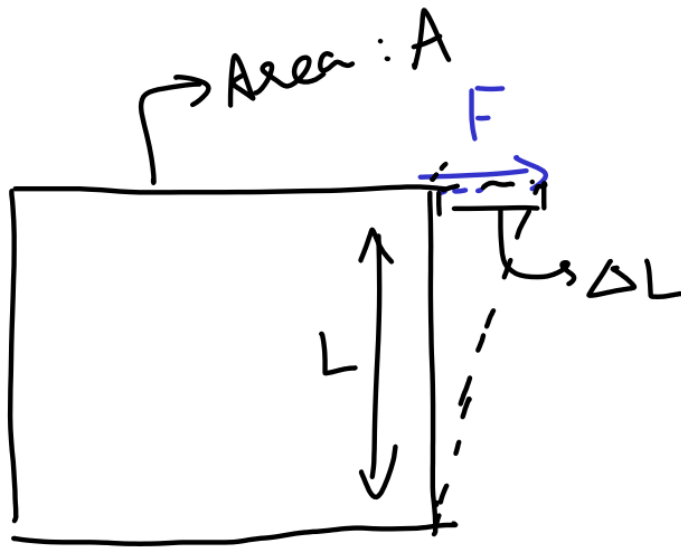


Figure 5: Sheer modulus

5. Observable matter:

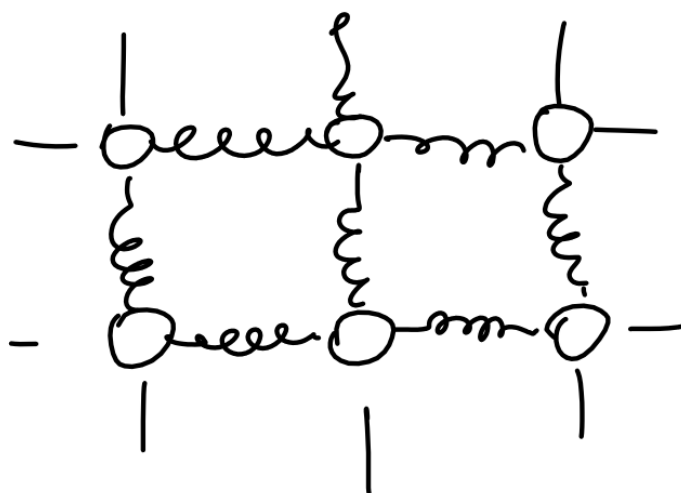


Figure 6: