WHAT IS SOFT MATTER ?

Examples:

1. Ink, Milk, Blood cells, Shampoo
2. Paints, Fevicol, Cord and our other food items.
3. Cell membranes, Soap Solutions, Proteins
4. Glassy materials, Molten plastic, Polymer solutions, Foam, Sponge.
5. Some aspects of sand-castles/sand piles and its collapse.
6. Other Biological systems: physics of cell motion, actin molecules, motion of molecules in ion channels accross membranes.

Are the above mentioned objects a list of *random different materials* OR
Can the material behaviour be understood by using *simple underlying physical principles?*

It turns out that quite a few of the properties of these materials are independent of the chemical details of the constituent molecules and its physical behaviour can be qualitatively understood by using simple models of statistical physics. Of course, quantitative prediction of properties of these materials necessitates the incorporation of chemical details.

Soft Matter is the **physics of macromolecules**: how do a suspension of macromolecules interact with each other and move around (dynamics)? The basic contituent molecules of soft matter can be broadly classified as:

- Colloidal suspensions (Brownian particles whose size can vary from nm to microns)
- Polymers (from a physicists point of view: long chains of connected particles all undergoing Brownian motion. Typical questions: what is the structure and net effective motion of the blob of particles? How do they structurally rearrange under flow?)
- Ampiphilic molecules capable of self assembly.

Interaction between macrmolecules are often entropic in origin.

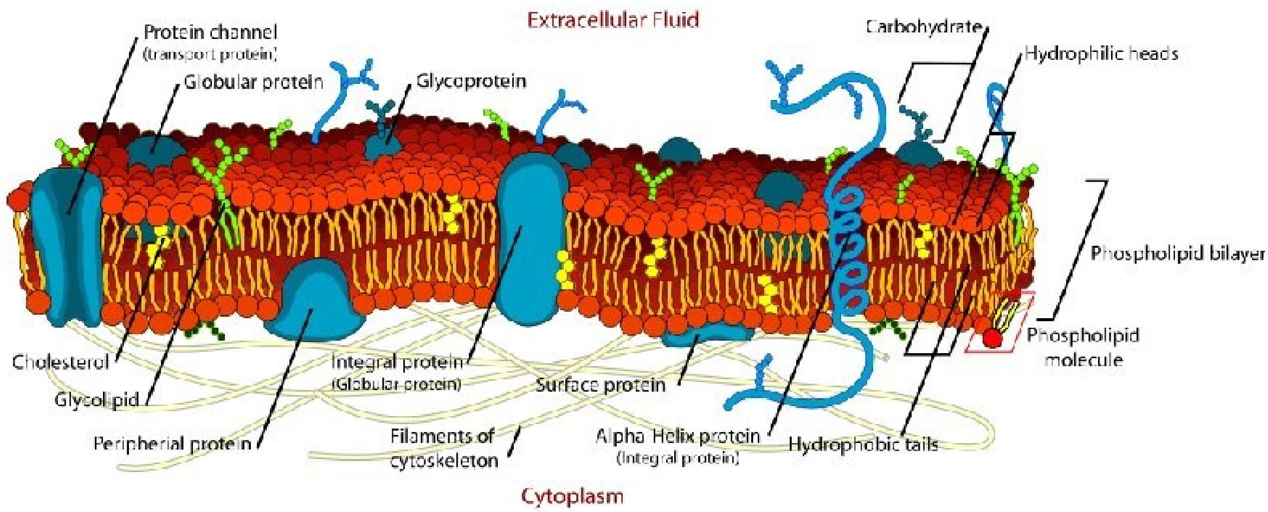
<u>What are the defining Characteristics of Soft matter systems?</u>

1. Large length and time scales of contituent particles. Time scales of motion are nano-seconds to seconds, i.e. much larger than atomistic time scales (femtoseconds).
2. Soft Matter shows large response under external perturbation (shear flow, Electric field).
3. Behaviour decided by entropic interactions: Large Thermal fluctuations.
4. Often very non-equilibrium systems: driven systems, active systems.

One is able to expand a rubber band to double its size by applying relatively small forces, because one is doing work against *entropic forces* instead of the forces originating from the chemical bond, i.e., reorganization of structure occurs at the macromolecular level instead of atomistic length scales. In contrast to standard condensed matter systems like metals and semiconductors, for soft matter systems quantum mechanical effects and quantum fluctuations can be ignored. This because the effective structure formed by constituent molecules is at length scales much larger than angstrom.

I attach two articles by two nobel prize winners P.W. Anderson and P.G. de Gennes who have been instrumental in laying the foundation of modern condensed matter physics. The content of one of the articles is based on the Nobel lecture delivered in the year 1992. The basic notions and ideas and aspects of interest in the field of condensed matter are best articulated in these articles.

An example of how a soft matter physicists tries to identify the principle mechanism of a certain phenomenon is illustrated below. Let us take the example of how a soft matter physicist will simplify and look at a model of a biological cell membrane whose picture is given below.



A cell membrane is constituted of complex and large chemical molecules called lipid molecule. It has a head from which emanates two tails of molecules. The head is surrounded by water and the cell membrane consists of 2 layers of lipid molecules suitably arranged. A question is: How is a cell membrane formed. Of course one can say it is formed by the balance of complex chemical interactions, but thats not how a physicist will look at it.

A physicist will focus on the most important property of the lipid molecule and leave out the chemical details of the problem. The lipid molecule has a water loving (hydrophilic) head and a water-hating (hydrophobic) tail. When a large number of such molecules are dispersed in water, the tails will try to avoid the water. The molecules will thereby arrange themselves in a bilayer such that the heads face the water and tails face away from the water and are in contact with other tails. And THAT is the simple principle by which lipid molecules *self assemble* and form stable cell membranes. Note that the main driving force in the formation of cell membranes is then the delicate balance of hydrophilicity and hydrophobicity of the head and tail respectively of the complex lipid molecule. See the right picture of the figure below.

And if instead of the water, the liquid in which the lipids were dispersed consisted of a mixture of water and oil (the tail of lipid has an affinity for oil), then the lipids will form a mono-later of molecules instead of a bilayer as shown in the left frame of the following picture. The green fluid can be assumed to be oil, and the white fluid is water.

Of course the structure that will be formed also depends on the relative ratio of the oil-water mixture or the concentration of the lipid molecules dispersed in the fluid.
By tuning these two quantities, one can actually get the lipids to self assemble in a wide variety of structures, inmcluding spheres, cylinders and stacks of plates.