

Center for Hierarchical Materials

Title: Phase Separation within Lyotropic Liquid Crystal Materials

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Lyotropic liquid crystal materials, lipids, block copolymers and other surfactants, have wide ranging application from detergents to delivery vehicles for RNA. Variation in the water/surfactant content can induce a wide range of phases, and substantial complexity can be introduced via variation in composition of both the surfactant and solvent phase. This rich compositional space within the formulations of such materials allows the tuning of many material properties at the microscopic and macroscopic scales. On the surfactant side, variation of surfactant charge, molecular size, spontaneous curvature all impact the CMC, the free unimer solubility, and the stability/thickness/viscosity of resulting interfacial films. Lipids on the other hand emerge from biological sources varying in headgroup chemistry and acyl tail thickness, altering the thickness and fluidity of resulting bilayers. Block copolymers offer substantial synthetic control of the polymer chemistry, molecular weight and block connectivity to drive a huge range of self-assembly phenomena.

When different types of lipids or surfactants are combined, there are frequently de-mixing phenomena which result in co-existing lyotropic phases. The co-existing phases may have quite different properties, depending on how the molecules partition. Some phases may be more readily assembled at regions of high curvature for instance. Surfactants with high negative spontaneous curvature can be expected

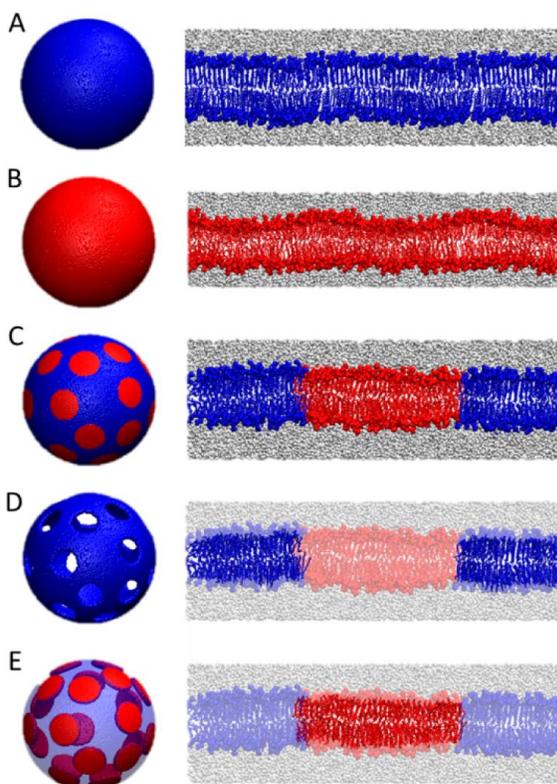


Figure 1. Changes in hydrophobic thickness, spontaneous vs. imposed curvature, aqueous region charge, and bending modulus can lead to lateral phase separation in the plane of lyotropic liquid crystal materials. Small angle neutron scattering (SANS) is a powerful tool which enables the selective contrast matching of distinct lipid phases. In this figure from Nickels et al JACS 2015, contrast enhanced SANS measurement were used to resolve the nanodomain structure in laterally phase separated lipid vesicles. The transparent coloration indicates regions of the bilayer that were contrast matched to the solvent, making them “invisible” to neutrons. (A) Liquid ordered phase, (B) liquid disordered phase, (C) nanodomain containing composition, non-contrast matched, (D) domain containing composition, contrast matched to emphasize the liquid ordered phase, and (E) domain containing composition, contrast matched to emphasize the nanodomains

to accumulate at and stabilize the boundary of soap bubbles; while a co-existing phase with low spontaneous curvature may exist within the film wall.

Lipid bilayers are one well-known example of phase co-existence where it functions to organize membrane proteins. In biological systems, the cell membrane can be composed of hundreds of types of lipids, each requiring highly specific enzymes for synthesis and a complex regulatory pathway. This results in a complex membrane composition, typically exhibiting co-existing phases. Cells invest a huge amount of energy into this regulation of membrane fluidity and organization. I have developed a number of scattering based approaches to study the lipid system which I believe will have application to the broader class of lyotropic liquid crystals.

Based on our previous studies, neutron scattering has been uniquely well-suited to interrogating the nanoscale organization of such materials. Broadly similar to SAXS, SANS using the scattering of neutrons to resolve the Angstrom to hundreds of nanometer length scale structure from many forms of soft matter. What is special to neutrons is that rather than scattering from electron density as x-rays do, neutrons scatter from atomic interactions, resulting in some unique sensitivity to light elements and in the case of hydrogen to its isotopes ^1H and ^2H . Through this, the scattering contrast of macromolecular assemblies can be tuned by isotopic substitution such as what we show in Figure 1. This is particularly useful in hydrogen rich systems – such as surfactants, lipids, and block copolymers!

Complementary methods are also envisioned. FRET is an example of a method which can be very useful for probing phase separation in lipids and other lyotropic liquid crystals. By selecting a FRET pair which are theorized to partition unequally between coexisting phases, it is often possible to extract compositional boundaries and describe the phase diagram. For large particles and phases, fluorescence imaging is an excellent tool to leverage this FRET concept and describe the individual phases.

As we gather to consider the many phenomena driving hierarchical assembly in soft matter, I propose a project to consider the existence, the design principles and emergent properties from materials containing co-existing lyotropic phases. Specific systems of interest will be determined from interactions with potential partners, but a few suggestions might be: (1) the accumulation of high curvature surfactants at the boundary regions of air/water/surfactant foams, (2) emergent assembly or organization of surfactant stabilized micro/nano particles containing coexisting surfactant phases, or (3) organization of surface molecules in lipid nanoparticles.