Investigating the micelle-like behaviour of alkylated metal organic cages for applications in phase transfer

Summer project with Dr Ben Pilgrim (bsp25@cam.ac.uk)

Self-assembled metal-organic capsules have been reported in a variety of solvent systems. Often however, a capsule is only soluble in a single solvent or a narrow range of similar solvents (e.g. only acetonitrile or only water), governed by factors such as the overall charge on the capsule, nature of any counterions and polarity of any peripheral substituents. Recently, capsules have been reported that are stable and soluble in two or more very different and immiscible solvents. Controlling the movement of capsules between such solvents is a crucial first step in developing more complex molecular separation techniques. Previous work has demonstrated that capsules A and B (Figure 1) (which carry a significant positive charge but also have long alkyl chains attached to their periphery) are soluble in both the polar solvent acetonitrile and in the non-polar solvent cyclohexane.

Figure 1: Self-assembly of capsules A and B

As cyclohexane and acetonitrile are immiscible, the phase transitioning properties of capsules A and B between these two immiscible solvents can be studied. When a substance is soluble in two immiscible solvents, the partition coefficient of the substance between the two different solvents, \( K \), (analogous to log P in pharmaceutical chemistry) can be measured. In this case for example, \( K = [A]_{\text{cyclohexane}} / [A]_{\text{acetonitrile}} \). Preliminary work has established that, as expected, as the length of alkyl chain is increased on capsule A, the partition coefficient increases, as the capsule increases its preference to reside in the non-polar cyclohexane. In theory, this partition coefficient, like all thermodynamic constants, should have a value independent of the total concentration of capsule across both phases, i.e. if the amount of capsule at equilibrium in one phase is doubled, then the amount in the other phase must also be doubled. However, with these capsules this ‘normal’ behaviour of the partition constant no longer holds and this now, apparent partition coefficient, becomes concentration-dependent.

Preliminary studies have shown that as the total concentration increases, the apparent partition coefficient increases and the capsules become more soluble in cyclohexane (Figure 2). Interestingly however, whilst the concentration of capsule in the cyclohexane phase (top) is much higher when the total concentration is increased, the concentration of capsule in the acetonitrile phase (bottom) falls at higher total concentration. This type of dependence is unprecedented to the best of our knowledge and warrants further investigation. We hypothesise this is due to a difference in the extent to which the anions dissociate from the cage in the different solvents and a micelle-like behaviour of the capsule at higher total concentrations in the less polar phase (due to association of the long alkyl chains).

This project will first look at quantifying this dependence, fitting the data against theoretical models to see what can be elucidated about the nature of the dissociation and finally seeking to apply this to problems in separation science.
One possible application of these results will build upon recent work in developing an azide-tagged capsule C (Figure 3). This capsule can undergo a ‘click’-type post-assembly modification via a strain-promoted azide-alkyne cycloaddition reaction with an *in situ* generated cyclooctyne reagent. The cyclooctyne reagent is only generated under irradiation of the appropriate cyclopropenone with UV light. Hence, a system has been developed whereby photo-induced phase transfer can be promoted. Further investigations are required to optimise the alkyl chain length considering our results on the concentration dependence of the partitioning of these types of capsules.

From the student’s perspective, this project would involve:

(a) Organic synthesis of the required dialdehydes, anilines and cyclopropenones. All syntheses have been well-optimised and so are known to work well and will give the student experience at performing a range of organic reactions.

(b) Self-assembly of capsules A, B and C.

(c) Investigation of the concentration dependence of the partition coefficient of these capsules between cyclohexane and acetonitrile using UV-Vis spectroscopy.

(d) Trying to fit the concentration dependence to existing theoretical models of the dissociation.

(e) Applying the results to the transport of cargo across phase boundaries.

References