Self-organization of rod-like viruses induced by multivalent counterions

Cheng WU*, Eric GRELET

CNRS-CRPP (Centre de Recherche Paul Pascal), Pessac, France

**wu@crpp-bordeaux.cnrs.fr*

In aqueous solutions, polyelectrolytes are surrounded by their counterions, where these screened like-charged objects are expected to repel each other. However, in the presence of multivalent counterions, a short range attractive force, called like-charged attraction, between polyelectrolytes is found to induce aggregation [1]. Several theories, like Oosawa model [2] and Wigner crystal model [3], have been proposed for this attraction, but no consensus exists for the precise mechanism. Self-assembly based on this attraction can form fascinating morphologies, such as DNA cholesteric liquid crystalline and columnar phases [4], crosslinked raft phase of F-actin [5] and bundles of filamentous viruses [1]. This multivalent ion driven attractive force, beyond depletion interaction, provides an alternative to induce effective attraction between rod-like colloids.

Comparing with the numerous works on DNA, fewer experiments have been done with filamentous fd viruses which are suitable model for self-organized system, thanks to their outstanding features: monodispersity in size, tunable rod flexibility, chemical and genetic modification ability, etc [6, 7]. In our work, fd viruses are condensed by using polyamines, e.g., Spermine (Spm^{4+}) and Spermidine (Spd^{3+}), as the inducing reagents.

The influence of concentration of polyamines has been investigated systematically. Three regions of polyamine concentration are separated by two critical values: condensation and resolubilization thresholds where aggregates of different morphologies form in between. Two original self-assemblies, 1D layered columns and 2D hexagonal platelets, are obtained close to the thresholds, as shown in Figure 1.

The aggregating process is much slower close to the thresholds, which leads to the formation of well-defined morphologies. Kinetic growth of the self-assemblies is investigated, forming—redispersing—reforming behavior is observed during the condensation of viruses. Phase behavior of the aggregates changes with virus rigidity, which is proved by using two kinds of mutants with different stiffness. Studies on the morphology and symmetry of the multivalent ion driven self-assemblies provide an efficient way to fabricate polyelectrolyte based ordered arrays.

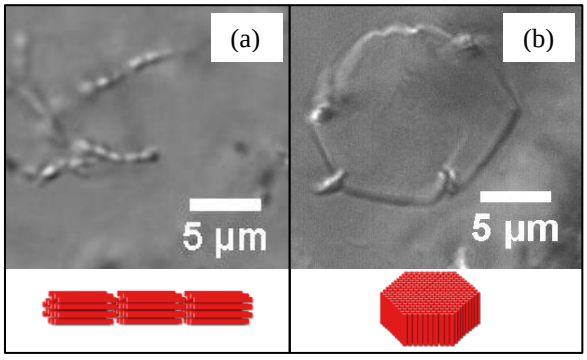

Figure 1 Differential interference contrast optical microscopy images of (a) layered columns and (b) hexagonal platelets of fd viruses induced by Spm^{4+} and Spd^{3+}, and schematic representation of their respective structure.

[1] J. Tang, et al, *Biophys. J.*, 2002, **83**, 566.
[2] F. Oosawa, *Biopolymers*, 1968, **6**, 1633.
[3] B.I. Shklovskii, *Phys. Rev. Lett.*, 1999, **82**, 3268.
[4] J. Pelta, et al, *Biophys. J.*, 1996, **71**, 48.
[5] G.C.L. Wong, et al. *Phys. Rev. Lett.*, 2003, **91**, 018103.
[6] E. Pouget and E. Grelet, *Langmuir*, 2013, **29**, 8010.
[7] Z. Zhang and E. Grelet, *Soft Matter*, 2013, **9**, 1015.