Entangled nematic colloidal dimers and wires

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The capacity to generate predetermined spatial arrangements of particles on different length scales is one of the central issues of nanotechnology. Current concepts rely on single atom and molecule manipulation by the sharp tip of the STM, particle manipulation by the laser or optoelectronic tweezers, microfluidics, and micromanipulation in combination with lithography. Of particular importance is 3D self-assembly, where the spatial arrangements of particles, such as photonic crystals, could be realized spontaneously.

Dispersions of colloidal particles in the nematic liquid crystal show an amazing diversity of patterns, such as chains [1] and 2D colloidal crystals [2], which are assembled by topological defects [3], which mediate the elastic distortion forces between the colloidal inclusions [4,5]. Recently, it has been predicted, that colloidal particles in the nematic liquid crystal could be assembled by delocalized defects or entangled topological defects in a form of single closed defect loops, extending over several colloidal particles [6]. In this case, one or several defect lines entangle two or many colloidal particles, which give rise to binding forces between the particles. Although primarily elastic in origin, these binding forces are a direct consequence of the nontrivial topology of the entangled director field, and can thus be considered as topological in nature.

Here we show experimentally and theoretically, that colloidal dimers and wires can be assembled by entangled topological loops of the nematic orientational field [7]. We have found that the colloidal entanglement proceeds exclusively via locally thermally quenching a thin layer of the nematic liquid crystal around selected colloidal particles, which explains why the entanglement has not been observed before. Three linear entangled defect structures have been found experimentally, which are topologically equivalent, but differ in the way of binding and in the particle separation. In all cases, the entanglement provides ten thousand times stronger binding compared to water-based colloids. This unique binding mechanism could be used to assemble optical resonator wave-guides, chiral colloidal wires and even more complex structures of topologically entangled colloids.

References:

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[3] Topological defects in a nematic liquid crystal are areas where the order parameter fields describing the molecular ordering are singular. A defect cannot be eliminated by a local continuous deformation of the nematic around the singularity. The formation of defects is a characteristic of symmetry breaking transitions.

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