Colloidal diffusion and viscoelasticity in blended solutions of supercoiled, ring and linear DNA

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We design topological blends of DNA that we can tune to exhibit a range of mechanical properties.

DNA is versatile model polymer with different topologies and sizes that can be precisely controlled. Through purification techniques and enzymatic treatment DNA can be transformed into linear, relaxed circular and supercoiled topologies.

Solutions of DNA exhibit intriguing viscoelastic properties that can be tuned by the DNA topology and concentration.

We create blends of DNA with varying topologies and concentrations to create complex fluids with viscoelastic properties that span from fluid-like to elastic behavior.

Our topological fluids and their characterization answer key questions in polymer physics and serve as a platform for creating new multifunctional ‘green’ materials.

We use particle-tracking to determine transport properties and viscoelasticity of DNA blends.

We embed fluorescent 1µm polystyrene microspheres into varying DNA blends. We use a fluorescence microscope to record 15-second videos of microspheres diffusing through the DNA blends. We use custom-written MATLAB particle-tracking code to track the trajectories of the diffusing beads.

We compute the mean-squared-displacements (MSD) of diffusing beads for each blend. From the MSDs we determine diffusion coefficients (D), transport coefficients (K) and diffusive scaling exponents (α). We also compute the elastic and viscous moduli (G', G'') to elucidate the viscoelastic properties of blends.

Semantic Supercoiled-Ring DNA Blends

We create semi-dilute blends of supercoiled and relaxed circular 45-kbp DNA. We determine how increasing the concentration of blends - from the semidilute to entangled regimes - impacts the diffusive and viscoelastic properties.

All blend concentrations display normal diffusion (MSD ~ t) indicating low levels of entanglements. Diffusion coefficients decrease with increasing concentration. Decrease in D is sharper at higher concentrations suggesting transition to the entangled regime.

Viscoelastic moduli of DNA blends show that most concentrations are in the unentangled terminal regime. In this regime G''~ω, G'~ω^1. Only the highest concentration shows signs of entanglements at high frequency (G'>G''). The complex viscosity shows nonlinear increase with concentration. The highest concentration shows higher viscosity and more shear-thinning - indicating the onset of entanglements.

The reptation time displays a similar non-monotonic dependence on blend fraction. The degree of entanglement depends on blend fraction. The reptation time is indicative of strain-induced disruption of entanglements.

Entangled ring-linear DNA blends exhibit emergent elasticity and subdiffusion due to threading of rings by linear chains.

50%-50% blends display the highest viscosity. All blends exhibit shear thinning indicating the presence of strain-induced disruption of entanglements.

Transport properties in blends exhibit a non-monotonic dependence on the linear mass fraction. Blends with equal mass fraction of linear and ring DNA exhibit the most extreme subdiffusion. This phenomenon is evidence of threading of rings by linear chains.

We create entangled blends of relaxed circular and linear 45-kbp DNA. We determine how varying the mass percentage of linear vs ring DNA in blends impacts the diffusive and viscoelastic properties.