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The Open-Access Journal for the Basic Principles of Diffusion Theory, Experiment and Application

Shear-flow mediated changes in DNA morphology

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1. Introduction

The behavior of DNA molecules in liquid flow is of interest in many different fields, since many processes in medicine and technology involve the transport and manipulation of long polymers such as DNA. Furthermore, due to its variability in length, DNA is a useful target for verifying theoretical polymer models. In contrast to former experiments on similar issues [1-3], we do not stain the whole molecule with bis-intercalating fluorescent dyes in order to visualize the DNA, but we label exclusively the non-tethered end with a nanometer-sized quantum dot (Qdot). This end-specific labelling has the considerable advantage over common approaches not to modify the intrinsic mechanical properties of the DNA and to allow reasonably long observation times due to significantly reduced bleaching.

2. Experimental

We attach the bifunctionalized DNA molecule specifically to the bottom of a microfluidic channel, while a Qdot is bound to the free end. Then the positions of that Qdot marked end is tracked over 10^4 frames from which subsequently the attachment point (center of movement) is calculated. In the force free case, those measurements allow the calculation of the end-to-end distance that characterizes the stiffness of the molecule, which is a fundamental mechanical property of polymers. Furthermore, the longest relaxation times are calculated from the time traces as the approximation of the autocorrelation function to a single exponential decay. To investigate the influence of different environmental conditions, the ionic strength of the surrounding phosphate buffer is systematically changed. Applying a shear flow causes stretching of the, for entropical reasons strongly coiled, molecule. The shear flow is characterized by the Weissenberg number W_i that is given by the product of the shear rate and the longest relaxation times. We determine again the positions of the Qdot labelled end in its dependence on the applied shear rate. Then the fractional extension of the molecule and the fluctuations around its mean position are calculated.

3. Results and Conclusion

The measurement of the free-end fluctuations without applied shear flow reveals the expected dependency of the mean square end-to-end distance on the ionic strength of the surrounding buffer. For lower ionic strength the stiffness of the DNA is increased resulting in an increased end-to-end distance [4]. However the measured values are systematically larger than expected at low ionic strength. These deviations are attributed to incremental self-avoiding effects. The calculated longest relaxation time of 0.5 s in a

100 mM phosphate buffer is in good agreement with reported values [5]. The fluctuations are symmetrical in the projection plane. When a shear flow is applied, the molecule is stretched. For small W_i, the extension increases linearly, while for larger W_i, a saturation at 80-90% of its contour length is reached. The fluctuations in flow direction and perpendicular to flow behave differently. The perpendicular fluctuations decrease continuously with increasing W_i while the fluctuations in flow direction run through a maximum for small W_i. This can be interpreted within a model of Brochard-Wyart [6] which describes the conformational transformation of the morphology of polymers for different stretching regimes. The observed large asymmetry in the fluctuations, especially for small W_i, is caused by the coupling of the fluctuations in flow direction with the fluctuations perpendicular to the surface to which the molecule is tethered due to the flow velocity gradient.

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