Topological flow in twisted open polymers: Plectoneme, belt-trick, and rotational friction

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The in-vivo functioning of DNA involves non-equilibrium dynamic twist effects that mostly have to do with the activity of various DNA-processing proteins [1]. In transcription, the process by which the DNA informational content is copied into a continuously growing RNA chain, it was suggested that a long nascent RNA chain might (either due to its own hydrodynamic friction or via anchoring to some other cellular component) provide enough rotational resistance to force the DNA strand to rotate around its own axis [2]. Experimental in-vivo and in-vitro studies found large degrees of DNA supercoiling upon transcription, being positive in front and negative behind the transcriptional complex [2].

Using scaling arguments and dynamic simulations, we study the torsional dynamics of a semiflexible polymer that is rotated at fixed frequency ω_0 at one end with the other end free [3]. We find a non-equilibrium transition at a critical frequency ω_*: In the linear regime, $\omega_0 < \omega_*$, axial spinning is the dominant dissipation mode. In the non-linear regime, $\omega_0 > \omega_*$, the twist-dissipation mode involves the continuous creation of plectonemes close to the driven end and the rotational friction is substantially reduced. This unique and highly nonlinear twist transport process is possible only for topologically open polymers, through a so-called "belt-trick" motion. Therefore, the rotationally-driven polymer can reduce the overall rotational friction as compared to the axial-spinning scenario, i.e., the plectoneme dissipation channel transforms the injected twist into writhing motion at very low frictional cost. This mechanism could be biologically relevant since it shows how transcription might produce positively super-coiled DNA structures that could favorably interact with negatively super-coiled nucleosomal structure ahead of the RNA polymerase even in topologically open systems and at very small energy expenditure.

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