Thermal fluctuations of an elastic filament confined in a fluid-filled channel

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Abstract.
A phenomenon that is exploited in material processing and that also arises naturally in material systems is the confinement of a flexible elastic filament within a long, hollow tube and the potential transport of that filament along the length of the tube. The movement or reptation of polymers confined within a tube like environment has been of interest for almost fifty years [1]. If a semi-flexible polymer strand is placed in warm water, it undergoes random transverse fluctuations driven by the thermal motion of the water molecules surrounding it. When fluctuating without constraint, the mean free energy of the filament is maintained at a certain level over time. However, if the range of fluctuations is limited due to a confining barrier then there will be a decrease in entropy and an increase in free energy of the filament, compared to the the values of entropy and free energy that prevail for unconstrained fluctuations. In addition, a pressure will be induced on the confining barrier which tends to resist further confinement [2]. The objective of the present work is to describe the general nature of that confinement and to propose a physical model that can serve as a basis for extracting a quantitative estimate of the magnitude of a driving force for translation of the filament along the length of the confining tube. The focus is on fluctuations of a single filament confned to a planar motion within a tapered channel, including fluctuations into the range of large deformation. By using Boltzmann statistical mechanics [3], values of the filament energy are determined for a range of accessible configurations. Then, applying the methodology of classical statistical thermodynamics, free energy values can be estimated from knowledge of the partition function. Finally, values of force or pressure can be determined from the free energy values.

References

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