Effects of Topological Constraint on the Relaxation of a Single Ring Polymer

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1 Introduction

The effects of topological constraints caused by the entanglement of polymers on the properties of polymer systems have attracted much attention. Especially, the static properties of a single knotted ring polymer, which is one of self-entangled systems, have been well studied[1]. In contrast, there have been few studies on its dynamic properties[2]. In this study, the effects of the topological constraints on the dynamic properties of a single knotted ring polymer are studied by Brownian dynamics simulations. The distribution of relaxation rates are estimated for a ring polymer with the trivial knot and the trefoil knot and the effects of the topological constraints on the relaxation rate distribution are clarified.

2 Model and Relaxation Rate

The Brownian dynamics simulations of a bead-spring model of a single ring polymer of N segments with the excluded volume interaction are performed. The hydrodynamics interaction is not taken into account. For the ring polymer, each relaxation rate is associated with a wave number p, because the ring polymer has the translational invariance along the polymer chain. The relaxation rates are estimated for each wave number p by the least square fit of data of an autocorrelation function C(p : t) to the double

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exponential function. Here,
\[ C(p : t) = \frac{1}{N} \sum_{i=1}^{N} \sum_{j=1}^{N} C(i, j : t) e^{-i \frac{2\pi}{p(i-j)}} \]
(1)
and \( C(i, j : t) \) denotes the equilibrium time-correlation function of the positions of the \( i \)th and the \( j \)th segments relative to the center of mass of the polymer. In the following, only the smallest relaxation rate \( \lambda_p \) for each wave number \( p \) is considered.

3 Result and Discussion

Figure 1 shows log-log plots of \( \lambda_p \) versus \( p/N \) for the trivial knot (a) and the trefoil knot (b). For the trivial knot, the relaxation rate distribution appears to satisfy \( \lambda_{p=1} \propto (1/N)^{2.18} \) and \( \lambda_{p>1} \propto (p/N)^{2.21} \). These exponents are similar to that of a linear polymer chain[3][4]. In the case of a linear polymer chain, the \( p \)th slowest relaxation rate \( \lambda_p \) behave as \( \lambda_p \propto (p/N)^{2.2} \). It should be noted that even in the case of the trivial knot the topological effect can be seen as the difference between the amplitude of the power law dependences of \( \lambda_{p=1} \) on \( 1/N \) and \( \lambda_{p>1} \) on \( p/N \), because there appears no such difference for a linear polymer chains. For the trefoil knot, it is characteristic that not \( p = 1 \) but \( p = 2 \) corresponds to the slowest relaxation mode for each \( N \). In comparison with the relaxation rate for the trivial knot, it is clearly seen the relaxation rates for the trefoil knot are larger for \( p = 1 \), and smaller for \( p > 1 \).

![Figure 1](image_url)

Figure 1: Log-log plots of \( \lambda_p \) versus \( p/N \) for the trivial knot(a) and the trefoil knot(b), respectively. The relaxation rates are denoted the black symbol for \( p = 1 \) and the white symbol for \( p > 1 \). The solid lines are given by the linear least square fit.

References