Elongation/Compaction of Giant DNA Induced by Depletion Interaction with a flexible polymer

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半屈曲性高分子と柔軟な高分子と溶媒の混合溶液系は、多様な秩序構造を形成する。しかし、それら秩序構造間の関係は十分に理解されてはいない。本研究では半屈曲性高分子の一種で、単一分子鎖レベルでの観察が可能な DNA と柔軟な水溶性高分子 Polyethylene Glycol(PEG) 水溶液を用いて単一 DNA 鎖のコイル-グロビュール転移とマクロ相分離による DNA 液晶相の形成について、実験的にその差異を明らかにした。また、自由エネルギーの観点からその二つの転移について議論した。

During the past few decades, increasing interests have been paid to phase segregation in soft matters. Among them, it is known that flexible polymer tends to cause segregation on stiff polymer with what is called depletion interaction[1]. Actually, formation of liquid crystalline phase from concentrated short DNA fragment solution is observed by the addition of a flexible polymer, Polyethylene Glycol (PEG), where DNA molecules are aligned parallel achieved by macroscopic phase segregation[2]. On the contrary, it is also known that a compact state of DNA is observed by the addition of PEG[3]. Thus, past literatures have indicated the opposite effect either elongation or compaction on DNA by a flexible polymer. The purpose of the present study is to obtain a comprehensive view on the segregation and the compaction of semiflexible polymer by the addition of flexible polymer.

Fig.1 represents experimental results. At dilute PEG conditions, a DNA molecule takes random coil state in spite of DNA concentration(fig.1 (a), (d)). With the increase of PEG concentration in semidilute DNA conditions it is found that DNA molecules exhibit extended conformation via macroscopic phase segregation(fig.1(b)), causing optically anisotropic(fig.1(c)). Whereas, individual DNA takes compact state via coil-globule transition in dilute DNA conditions(fig.1(e)). The long axis length of elongated state is 10^3 times larger than that in the compact one. It is to be noted that, the macroscopic phase segregation is to be generated at lower PEG concentration than the compaction.

The free energy change are calculated with a simple argument. The results are shown in Table.1, indicating that in both transitions, the absolute values of ΔF_{dp} and ΔF_{el} are same order.
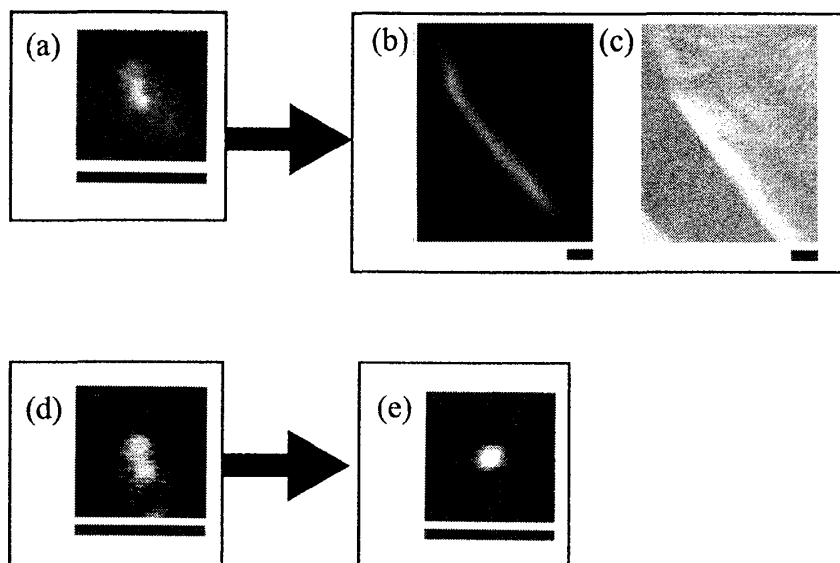
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Figure 1: DNA conformations induced by the existence of PEG. All scale bar represents 5 μm. (a) coiled DNA molecule in concentrated DNA solution (DNA 20 μg/ml, PEG 170 mg/ml, NaCl 100 mM). (b) elongated state of DNA molecule embedded in a liquid crystal, which was generated by a phase segregation to DNA rich phase and PEG rich phase from uniform phase.(DNA 20 μg/ml, PEG 230 mg/ml, NaCl 100 mM). (c) the polarization microscopic image of the identical region as (c). (d) coiled DNA molecules in dilute DNA solution (DNA 0.1 μg/ml, PEG 170 mg/ml, NaCl 100 mM). (e) compact state of DNA in dilute DNA solution(DNA 0.1 μg/ml, PEG 230 mg/ml, NaCl 100 mM).

Table 1: Free energy change involving PEG/DNA

	$\Delta V/nm^3$	$\Delta F_{dp}/kT$	R_D/nm	$\Delta F_{el}/kT$
elongation	$-1.2 \cdot 10^6$	-900	$5 \cdot 10^4$	+700
compaction	$-3.6 \cdot 10^6$	-3000	70 [4]	+2000

ΔV describes volume change in depletion layer for PEG. ΔF_{dp} represents the gain in the decrease of depletion layer for PEG per single DNA chain. R_D is the long axis length of DNA molecule after transition. ΔF_{el} describes the loss in elastic part of the free energy for a single DNA chain.

References

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