# Semiflexible filamentous virus particles on freestanding lipid membranes: Conformations, membrane-assisted self-assembly, and membrane-driven collapse

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## Abstract

In spite of extensive experimental and theoretical efforts, understanding of the mechanisms of interaction of macromolecules and filament-shaped macromolecular assemblies with freestanding lipid membranes is far from being complete, and many questions related to role of local perturbation of the membrane properties in these interactions still need to be resolved. Semiflexible biopolymers and biologically-derived colloidal particles, such as DNA and filamentous phages, are excellent objects to address these issues experimentally.

Previously, we have found[1,2] that interaction of DNA molecules with strongly charged freestanding cationic lipid bilayers[3] leads to membrane-driven coil–globule transition of membrane-absorbed DNA macromolecules. This effect is a result of local membrane deformations created upon electrostatic binding of a DNA molecule to lipid membrane[4]. This naturally brings up a question on the role of the polymer bending elasticity in the macromolecule–membrane interactions.

To address the effect of stiffness of membrane-adsorbed particles in these phenomena, we have recently studied[5] the behavior of much more rigid semiflexible *fd* virus particles (contour length $L_0$ = 880 nm, diameter $d$ = 6.6 nm) and *fd* polyphages (contour length $L_m = mL_0$, $m$ = 2–11) electrostatically adsorbed on freestanding cationic lipid membranes. The persistence length of *fd* virus in bulk aqueous media has been previously reported to be in the range of 2.0–2.8 μm.

In our experiments, we varied both the surface charge of cationic lipid membranes and the surface density of membrane-adsorbed *fd* virus particles.

When *fd* virus particles are adsorbed at a low surface density to a weakly charged membrane, they behave as individual non-interacting semiflexible filaments exhibiting Brownian motion and conformational fluctuations. Based on the analysis of conformations of membrane-bound polyphages with the contour length up to ~10 μm, we found that membrane-adsorbed *fd* virus is characterized by the persistence length of ~ 2.4 μm, which is in a good agreement with previously reported values for *fd* virus in bulk aqueous media.

An increase in the surface density of *fd* virus particles absorbed to weakly charged freestanding membranes leads to a drastic qualitative change in their behavior. In this case, we observed membrane-driven self-organization of the virus particles: They form long linear tip-to-tip chain aggregates, which exhibit dynamic assembly-disassembly and transient branching. This behavior is in qualitative agreement with results of recent computer simulations of rod-like particles on responsive elastic sheets[6].

On the other hand, at higher membrane charge densities we find that membrane-driven interactions are strong enough to induce the membrane-driven collapse of the relatively stiff *fd* virus particles into sub-resolution-sized globules. This effect shows a striking similarity to the membrane-driven collapse of much softer DNA molecules on freestanding cationic lipid membranes.

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