Micromechanics of Nucleic Acids

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Brief review of scanning probe microscopy visualization of RNA and DNA molecules is presented. Nucleic acids molecules were absorbed on clear and modified surfaces of mica. The relaxation process of nucleic acids molecules is observed on the support substrate. The influence of hydrodynamic flow and electrostatic repulsion on the adsorbed molecule orientation is found. The adhesion energy and the rigidity of the molecules are estimated. The difference in the RNA adsorption on surfaces of modified mica and modified graphite is discussed.

The observed formation of various forms of adsorbed nucleic acids in the presence of different chemical reagents is interpreted in the terms of micromechanics.

1. Introduction

Recently, the use of the atomic force microscopy for studying molecular and biological objects has become more and more extensive [1–3]. Atomic force microscopy gives a lot of advantages in comparison with other methods, because it does not need special conditions, such as vacuum or special pre-deposition processing. However, the preparation of the samples for AFM study plays a large role. Differently prepared samples of the same object sometimes provide us different visual data.

The deposition process of DNA molecules onto a mica surface for imaging using the atomic force microscopy was described in Ref. [4]. In the present work we have obtained the images of the RNA molecules, which were rinsed with water after their adsorption on the substrate. So, this hydrodynamic flow stretched chains of the RNA molecules and determined their orientation. As a rule, the molecules are fixed to the substrate in their middle part or at the edges. Therefore on the AFM images there are two kinds of the loops: (1) loops that are fastened in the middle and (2) those fastened at the edges (Fig. 1). Two

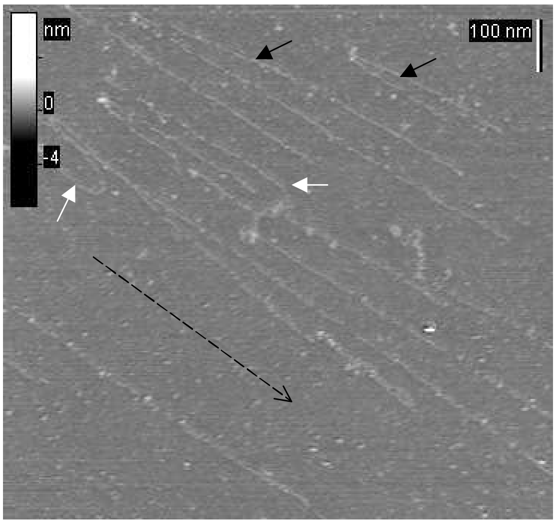

Figure 1. Typical images of RNA loops. Two types of loops are shown: (1) loops that are fixed to the substrate in the middle (black arrows) and (2) those fixed to the substrate at the edges (white arrows). The flow direction is shown with dotted arrow.

crucial factors, hydrodynamic pressure and electrostatic repulsion, determined the conformation of the absorbed molecules during deposition from solution.

The parameters of absorbed loops were estimated. The angle between the parts of the RNA molecules as a function of their charge was calculated for the model of charged rigid chain. For typical angles obtained in the experiments, this model gives us charges from several to several tens of electrons.

2. Model and results

In the theoretical model it was assumed that there is no charge at the point of adhesion of the RNA molecule to the massive (compared with the molecule) substrate. The charge is assigned to the molecule discretely and equidistantly so that the sum of these elementary charges is the full charge of the molecule and is the main parameter of the model. In order to describe the influence of the hydrodynamic flow, the RNA chain was presented as a chain of balls and the Stock's law was applied to them:

$$F = 6\pi r\eta v,$$

where F is the force acting on the ball, r is the ball radius, η is the viscosity of water, and v is the speed of the flow.

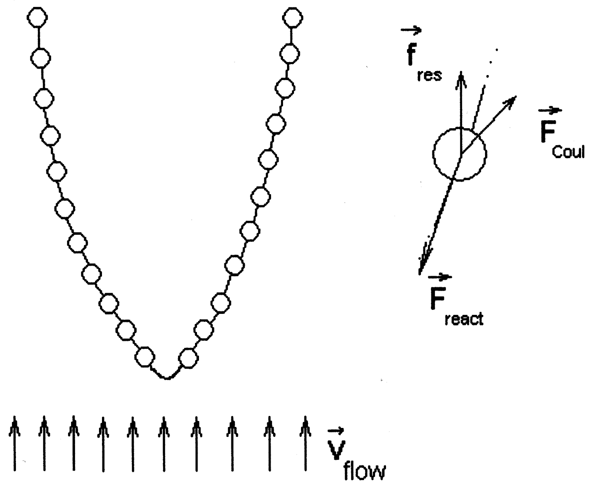

Figure 2. The model of an RNA molecule used to calculate its shape. F_{react} is the elasticity force, F_{Coul} is the total electrostatic force, f_{res} is the resistance force, v_{flow} is the hydrodynamic flow velocity.

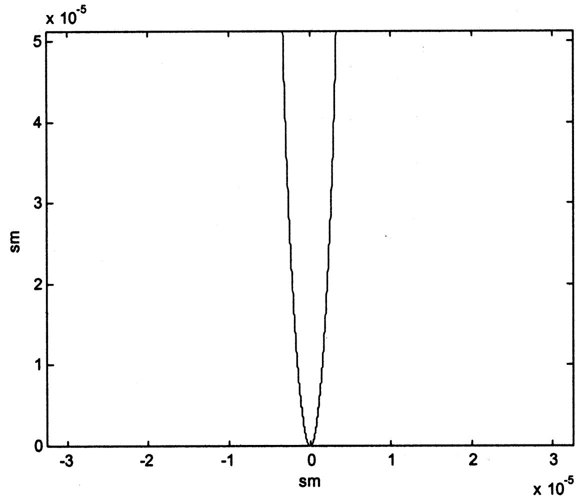

Figure 3. Calculated shape of the RNA molecule. (The flow velocity is 10 cm/s).

The model is shown in Fig. 2. It can be used for any other extensive charged molecules.

This model yields the following results: (1) the shape of the molecule is shown in Fig. 3, (2) the total charge of the molecule with the length of 1 μm is

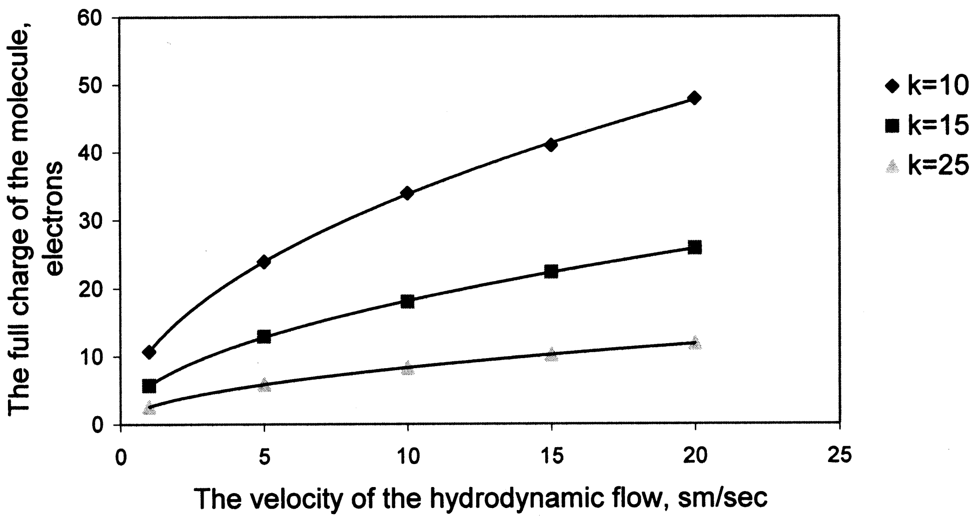

Figure 4. Full charge of the molecule as a function of the flow velocity for three different values of parameter k (see the text).

18 electrons.

Full charge of the molecule as a function of the hydrodynamic flow velocity for different values of the parameter k is shown in Fig. 4. Parameter $k = y_e/x_e$ is the ratio between the ordinate and abscissa of the edge of the molecule (see Fig. 3) or, in other words, it characterizes the angle at the bottom of the loop. We obtained that the full charge is proportional to the square root of the flow velocity: $Q \sim \sqrt{v}$ (see Fig. 4).

3. Conclusion

Atomic force microscopy yields direct information on the conformation of RNA molecules allowing to define various characteristics of the molecule. We have estimated the charge of adsorbed RNA molecules aligned by the hydrodynamic flow.

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