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RNA Nanotubes**

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# Discrete-to-Continuum Models for Biomedical Applications of RNA Nanotubes

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**Abstract**—RNA macromolecular structures are very important in the currently boosting field of bionanotechnology, including a range of biomedical applications. In order to expand the applications of these RNA nanoclusters obtained from the self assembly of the ribonucleic acid (RNA) building blocks, it is critical to be able to better understand and predict their properties. Therefore, we model the RNA nanotubes of different sizes using molecular dynamics simulations and then study the mechanical properties of such nanotubes with continuum models implemented with the finite element methodology. We present details of our novel discrete-to-continuum models, and explain how the atomistic models in this field can be used to develop the continuum macroscopic models which would allow to calculate elastic properties of RNA nanotubes using the finite element method. By using the elastic constants available for nucleic acids, we demonstrate how to obtain the distribution of the displacement field due to stress along different directions of the RNA nanotube. These new results pave the road to our better understanding of RNA nanotube stability in biomedical applications.

## I. INTRODUCTION

The potential application of ribonucleic acid (RNA) nanoclusters in nanobiomedicine becomes more feasible because of flexible nature of their structures. In the current era of modern nanotechnology, the nucleic acid nanotechnology research attracts increasing attention in biomedical and bioengineering applications [1], [2]. For these applications it is very important to be able to achieve the proper self assembly of the RNA building blocks.

As of today, nanomechanical properties of the collagen fabril proteins have already been studied at large deformation of the molecules [3], [4]. Furthermore, for carbon nanotubes (CNT), that have similar physical structures as RNA nanotubes, the atomistic to continuum modeling has also been performed using the finite element method [5], [6] to calculate elastic properties of CNT under stress. The experimental and theoretical studies have been performed to calculate the elastic constants like Young's moduli of polymer-like polyvinyl alcohols and polyethylene [7], [8], [9]. Additionally, the continuum and particle based models for DNA systems have been studied, where the results related to discrete base-pairs have been used to approximate the properties for a continuum rod-like model to study their mechanical properties [10]. In a very recent

study, the DNA double-helix has been used to find the effect of its structural characteristics on mechanical properties, including elasticity [11]. The continuum model approximation can also be extended in the study of protein-protein interactions, protein-nucleic acid interactions, as well as for finding the relative stability of A and B forms of deoxyribonucleic acid (DNA) [12], [13]. These works provide an initial foundation for our development of atomistic to continuum models for studying mechanical properties of RNA nanotubes as the main goal of this paper.

The modeling and calculation of properties of RNA nanotubes using molecular dynamics simulations have been performed in earlier studies [14], [15]. The building blocks used for these RNA nanoclusters are well known. They are RNAI and RNAII and are defined as the sense and anti-sense plasmids that control the replication of COLE1 [16], [17]. COLE1 is a DNA molecule separated from the chromosomal DNA that is found in the cells of bacteria. The sequence for the RNAI is (GGCAACGGAUGGUUCGUUGCC) and that for the RNAII is (GCACCGAACCAUCCGGUGC) [18]. However, as of today, very limited results are known for elastic properties of such RNA nanoclusters. Therefore, in this paper we aim at filling this gap. We will develop novel models where the atomic level elastic parameters will be used to calculate the elastic properties of RNA nanoclusters such as nanotubes, with continuum-type models based on their finite element implementations.

## II. THEORY AND COMPUTATIONAL METHOD

In our present study the structure of the RNA nanotube is approximated by a hollow cylindrical shell similar to a continuum representation of carbon nanotubes. Therefore, the development of model formulation to study mechanical properties of RNA nanotubes can proceed in a similar manner as that used for carbon nanotubes in the earlier studies where the resulting calculations were based on the finite element method [5], [6]. The development of discrete-to-continuum models for other systems presenting interest here can be found in [19], [20].

In order to study the properties of biological systems, such as ours, at larger scales it is very important to develop the

model equations that include the properties coming from the inter-atomic interactions calculated using the atomic level investigations. Assuming the motion of the atoms in the molecule as a simple harmonic motion, the energy contribution from bond stretching, bond bending and dihedral angle torsion are expressed as

$$V_r = \frac{1}{2} k_r (r - r_0)^2, \quad (1)$$

$$V_\theta = \frac{1}{2} k_\theta (\theta - \theta_0)^2, \quad (2)$$

and

$$V_\phi = \frac{1}{2} k_\phi (\phi - \phi_0)^2, \quad (3)$$

where  $k_r$ ,  $k_\theta$  and  $k_\phi$  are the bond stretching, bond bending and the dihedral angle torsional force constants for the biomolecular system under consideration. Here  $r_0$ ,  $\theta_0$  and  $\phi_0$  are the distance, angle, and dihedral angle at equilibrium, respectively. In the continuum model, let us take a small element of the RNA nanotube of length  $L$  and diameter  $d$ . Suppose the  $\Delta L$ ,  $\Delta\theta$ , and  $\Delta\phi$  are the stretch, bending and the torsional displacement in the cylindrical element of the tube. Now the corresponding part of energy (i.e. energy due to elongation) in the continuum model for this cylindrical shell can be expressed as:

$$U_A = \frac{1}{2} \frac{YA}{L} (\Delta L)^2, \quad (4)$$

where  $\Delta L$ ,  $Y$ ,  $L$  and  $A$  are the corresponding infinitesimal values along the axial direction, that is the length of the element, Young's modulus, and the cross-sectional area of the RNA nanotube.

Next, to account for the bending phenomena with moment of inertia  $I$  and with bending angle  $\alpha$ , the expression for the elastic energy is given by

$$U_M = \frac{1}{2} \frac{YI}{L} (2\alpha)^2. \quad (5)$$

Finally, the energy corresponding to the rotational motion of the cylindrical element can be expressed as

$$U_A = \frac{1}{2} \frac{GJ}{L} (\Delta\beta)^2, \quad (6)$$

where  $\Delta\beta$  is the rotation of the one end around the other caused by the elastic torsion in the beam element of the cylindrical RNA nanotube, and  $G$  is the shear modulus.

From the above relations, it can be deduced that the quantities  $V_r$ ,  $V_\theta$  and  $V_\phi$  are the bond stretching energy, bond bending energy and the torsional energy corresponding to the atomistic scale which are equivalent to the corresponding energies derived for a finite element representation of the RNA nanotube, assuming its continuum approximation. From comparison of the corresponding energies at these two different scales we find that

$$\frac{YA}{L} = k_r, \frac{YI}{L} = k_\theta, \frac{GJ}{L} = k_\phi. \quad (7)$$

Now, analyzing the above relations further, one can see that the elastic parameters in the continuum model can be predicted from the parameters obtained from the atomistic calculations.

Specifically, the quantities  $k_r$ ,  $k_\theta$ , and  $k_\phi$  can be calculated by using the molecular dynamics simulation technique.

For most nucleic acid based structures of interest here, a linear relationship between strain and stress can be assumed. For a linear and isotropic continuum system, the components of stress tensor in terms of the elastic coefficients and strain can be expressed as

$$\begin{bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{23} \\ \sigma_{13} \\ \sigma_{12} \end{bmatrix} = \frac{Y}{(1+\nu)(1-2\nu)}$$

$$\begin{bmatrix} 1-\nu & \nu & \nu & 0 & 0 & 0 \\ \nu & 1-\nu & \nu & 0 & 0 & 0 \\ \nu & \nu & 1-\nu & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1-2\nu}{2} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1-2\nu}{2} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1-2\nu}{2} \end{bmatrix} \begin{bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ \varepsilon_{23} \\ \varepsilon_{13} \\ \varepsilon_{12} \end{bmatrix}$$

, where the quantity  $Y$  is Young's modulus and  $\nu$  is the Poisson ratio. The latter is given by the relation:

$$\nu = \frac{3K-2\mu}{(3K+\mu)}, \quad (8)$$

where the quantities  $K$  and  $\mu$  are the bulk modulus and the shear modulus, respectively. For a linear, homogeneous and isotropic system, such as our continuum representation of RNA nanotubes, the elastic motion is governed by

$$\sigma_{ij,j} = 0, \quad i, j = 1, 2, 3, \quad (9)$$

with the Cauchy type relationship between the displacement and strain:

$$u_{ik} = \frac{1}{2} \left( \frac{\partial u_i}{\partial x_k} + \frac{\partial u_k}{\partial x_i} \right), \quad i, k = 1, 2, 3. \quad (10)$$

Furthermore, the formulation of constitutive strain-stress relationships can also be finalized, once the elastic parameters (in particular, Poisson's ratio and elastic moduli of the system) are available. In our case, we will use the elastic moduli calculated from the atomistic modeling and obtained from the experimental techniques reported in the literature.

As a first step, modeling of the self assembly of RNA nanoclusters has been performed by using molecular dynamics (MD) simulations. For MD simulations we have used the CHARMM27 force field [21] implemented by the software package NAMD [22]. In order to study the mechanical properties of RNA nanoclusters we have used the finite element method implemented by COMSOL multiphysics. For solving the elastic equations we have used the general partial differential equation representation methodology, available in that software.

A series of numerical experiments have been carried out with the developed discrete-to-continuum model, subjected to different boundary conditions. For example, we have used the

Dirichlet boundary conditions at both ends of the nanotube in such a way that one its end has been displaced by a function of time, while the other end has been kept fixed. A representative example, presented here was based on the following conditions:  $u_i = 0$  at  $z=0$  ( $i = 1, 2, 3$ ) and  $u_1 = 0.1t$ ,  $u_2 = u_3 = 0$  at the other end. In our examples presented in the next section  $z=40$  nm. On the other cylindrical surfaces, the von Neumann boundary conditions have been imposed such that the flux is zero, i.e.  $n \cdot \sigma = 0$ .

All results presented in the next section have been obtained through the grid refinement procedure, so that the convergence was guaranteed. We note also that model (9) allows a straightforward generalization to the time-dependent case.

### III. RESULTS AND DISCUSSION

Based on the developed discrete-to-continuum model framework, we approximate the systems of RNA nanoclusters by continuum systems, where the approximate density of a RNA cluster will be represented by the ratio of the total mass to the corresponding volume of the cluster. For example, in the case of 5 ring RNA nanotube the approximate volume of the cluster is

$$V = 4.42 \times 10^{-24} \text{ m}^3$$

and mass is

$$M = 8.5 \times 10^{-22} \text{ kg.}$$

In this case, the density is calculated as

$$\rho = M/V = \frac{8.5}{4.42} \times 10^2 \text{ kg/m}^3,$$

and in the calculations reported here we have taken  $\rho = 190 \text{ kg/m}^3 = 0.190 \text{ g/cm}^3$ . The same procedure is applied to other nanotubes. Namely, the mass and the volume of the system we study are determined by adding the masses and volumes of individual atoms in the corresponding RNA nanotube.

As an example, the optimized structure of 10 ring RNA nanotube is presented in Figure 1, while the corresponding continuum structure is presented in Figure 2. During the modeling of the system we have used the VMD tool and topotool to connect the bonds between the fragments. Recall that the building blocks for the RNA nanotube are the small double strand RNA complexes RNAlI/RNAlII. Those are taken from the protein data banks with the pdb code (2bj2.pdb) [18]. The assembling of the fragments is done via tcl scripting in the VMD. In order to describe the properties of the system based on the continuum model we have used the constitutive relationships between strain and stress tensors, as described in the previous section. The values for the elastic coefficients of the soft materials such as nucleic acids are available in the literature. They have been used for calculating elastic properties of the system based the continuum approximation of the RNA nanocluster. In our calculations presented here we have used the Poisson ratio and Young's modulus that have been used for nucleic acid systems. These values are 0.40 and 300 MPa i.e  $3 \times 10^8$  PA, respectively, and they have

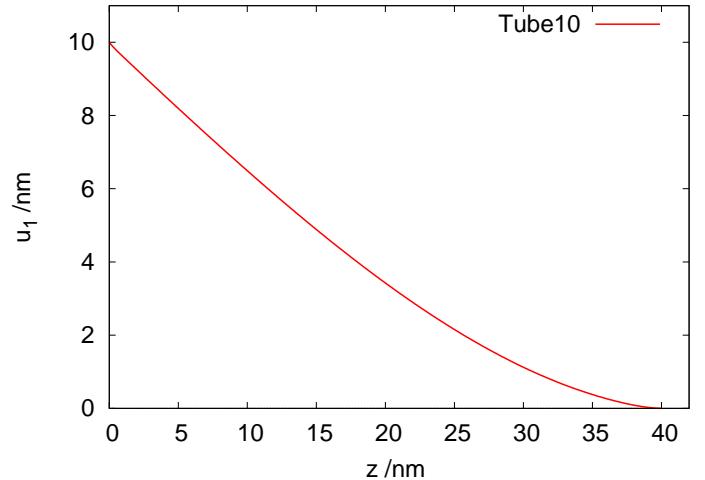


Fig. 4. The results for the displacement along the direction of the axis of the RNA nanotube of size 40nm (10 ring) as a function of position using finite element method

been obtained by using experiment and atomistic calculations as reported, e.g., in [23]. Using the strain-stress constitutive relationships within the developed discrete-to-continuum model framework, we have calculated the displacement field of the RNA nanotube presented in Fig. 1. The diameter of the nanotube in this case is around 5nm. This value is consistent with the approximate diameter value of the RNA nanotube modeled with molecular dynamics simulations. The results for the displacement field at different positions along the RNA nanotube consisting of 10 rings (that is 40 nm in length) have been obtained by using the finite element method, as described in the previous section. They are presented in Figure 3. During these calculations of the displacement field, induced by the applied stress in the continuum model of the RNA nanotube, we have used displacements at the one end of the tube, while the other end has been fixed via Dirichlet boundary conditions. After simulating the system for 100ns, we have calculated the distribution of the displacement field as a function of z, i.e along the direction of the axis of the RNA nanotube as defined above (the tube of 10 rings is 40nm in length). The results are presented in Figure 4. From the analysis of the displacement field, we conclude that the displacement is continuously decreasing as we move to the fixed end of the RNA nanotube. This means that the developed model can be used for larger RNA nanotubes, consisting of 20-30 nanorings, which are needed for real biomedical applications. Such systems cannot be analyzed efficiently with atomistic type models due to prohibitive computational cost.

### IV. CONCLUSIONS AND OUTLOOK

In the current work we have studied the mechanical properties of RNA nanoclusters using the finite element method. The original self assembly of the RNA nanocluster has been modeled by using the molecular dynamics simulation technique. A novel atomistic-to-continuum model has been developed. We have approximated the RNA nanotube by a

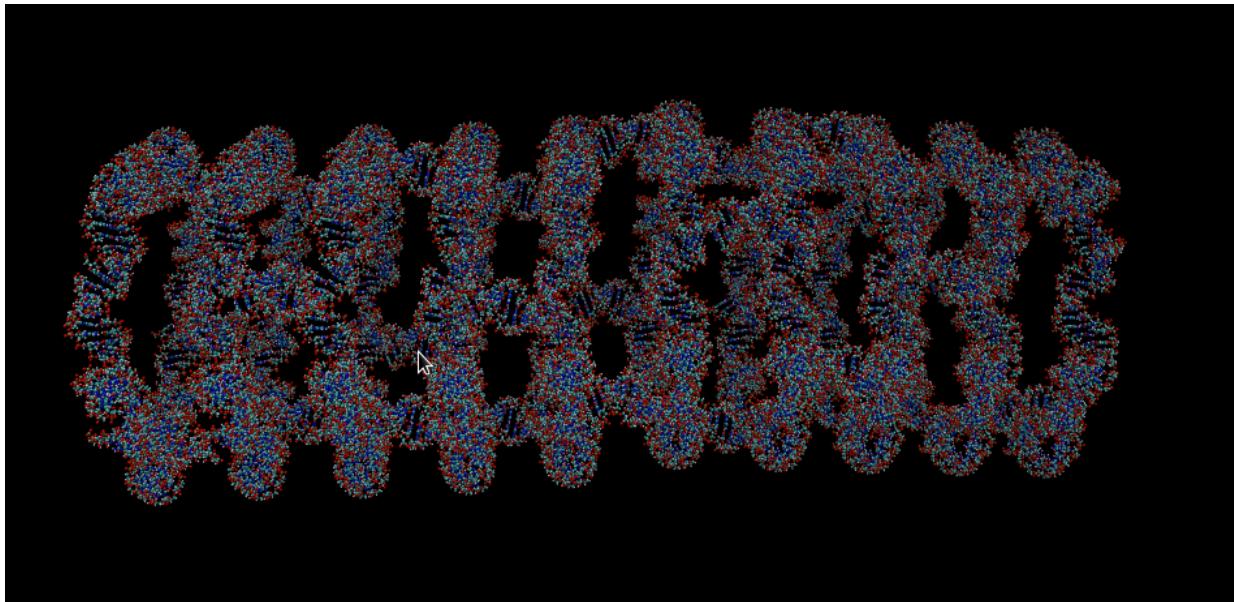


Fig. 1. A representative example of RNA nanotube modeled based on 10 nanorings

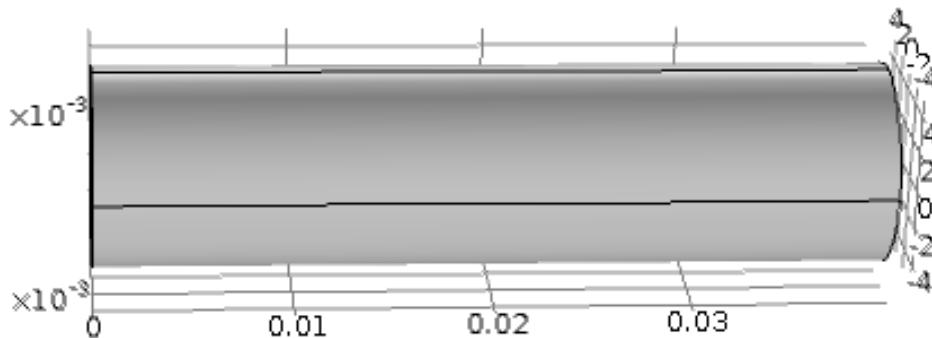


Fig. 2. Approximated continuum geometry of the RNA nanotube as a hollow cylindrical shell

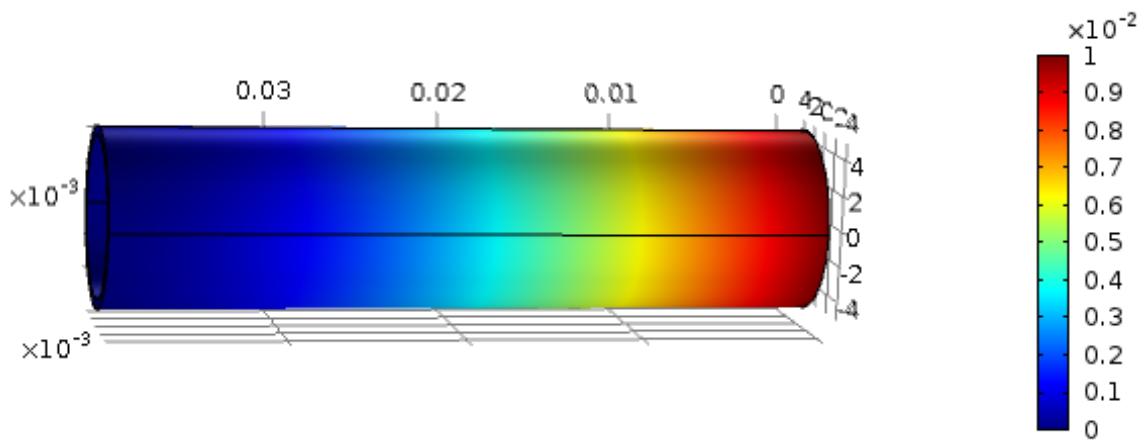


Fig. 3. Distribution of the displacement due to stress along a 10 ring RNA nanotube using the finite element method (presented at simulation time of 100ns)

hollow cylindrical shell with uniform distribution of atomic system characteristics. The length and the radius of such a

continuum system have been approximated by the dimensions of the corresponding all atom structure. This has allowed

us to study the elastic properties of the system by using the linear constitutive relationships between strain and stress. Several types of boundary conditions have been analyzed. For example, applying Dirichlet boundary conditions, we reported the results on mechanical characteristics of the entire volume for the simulation time of 100ns. From the obtained results, we observed that when one end of the tube is fixed, the stress is increasing as the distance from the fixed end of the nanotube increases. This behaviour has been elucidated based on the distribution of displacement field through the entire volume. The displacement field as a function of the distance along the direction of the RNA nanotube has been analyzed in detail. The results on the volume and densities have also been presented. The developed discrete-to-continuum model could pave the way to the analysis of stability of longer RNA nanotubes, consisting of 20-30 nanorings, which is important for many current and potential biomedical applications of these systems.

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## REFERENCES

- [1] P. Guo, "RNA nanotechnology: Engineering, assembly and applications in detection, gene delivery and therapy," *J Nanosci Nanotechnol*, vol. 5, no. 12, pp. 1964–1982, Dec. 2005. [Online]. Available: <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2842999/>
- [2] E. Osada, Y. Suzuki, K. Hidaka, H. Ohno, H. Sugiyama, M. Endo, and H. Saito, "Engineering RNAProtein complexes with different shapes for imaging and therapeutic applications," *ACS Nano*, vol. 8, no. 8, pp. 8130–8140, Aug. 2014.
- [3] M. J. Buehler, "Nanomechanics of collagen fibrils under varying cross-link densities: Atomistic and continuum studies," *Journal of the Mechanical Behavior of Biomedical Materials*, vol. 1, no. 1, pp. 59–67, Jan. 2008.
- [4] B. Depalle, Z. Qin, S. J. Shefelbine, and M. J. Buehler, "Influence of cross-link structure, density and mechanical properties in the mesoscale deformation mechanisms of collagen fibrils," *Journal of the Mechanical Behavior of Biomedical Materials*, vol. 52, pp. 1–13, Dec. 2015.
- [5] H.-C. Cheng, Y.-L. Liu, Y.-C. Hsu, and W.-H. Chen, "Atomistic-continuum modeling for mechanical properties of single-walled carbon nanotubes," *International Journal of Solids and Structures*, vol. 46, no. 78, pp. 1695–1704, Apr. 2009.
- [6] K. I. Tserpes and P. Papanikos, "Finite element modeling of single-walled carbon nanotubes," *Composites Part B: Engineering*, vol. 36, no. 5, pp. 468–477, Jul. 2005.
- [7] T. Odijk, "Elastic constants of nematic solutions of rod-like and semi-flexible polymers," *Liquid Crystals*, vol. 1, no. 6, pp. 553–559, Nov. 1986.
- [8] K. Tashiro, M. Kobayashi, and H. Tadokoro, "Calculation of Three-Dimensional Elastic Constants of Polymer Crystals. 1. Method of Calculation," *Macromolecules*, vol. 11, no. 5, pp. 908–913, Sep. 1978.
- [9] ———, "Calculation of Three-Dimensional Elastic Constants of Polymer Crystals. 2. Application to Orthorhombic Polyethylene and Poly(vinyl alcohol)," *Macromolecules*, vol. 11, no. 5, pp. 914–918, Sep. 1978.
- [10] R. S. Manning, J. H. Maddocks, and J. D. Kahn, "A continuum rod model of sequence-dependent DNA structure," *The Journal of Chemical Physics*, vol. 105, no. 13, pp. 5626–5646, Oct. 1996.
- [11] Y.-J. Kim and D.-N. Kim, "Structural Basis for Elastic Mechanical Properties of the DNA Double Helix," *PLOS ONE*, vol. 11, no. 4, p. e0153228, Apr. 2016.
- [12] P. A. Kollman, I. Massova, C. Reyes, B. Kuhn, S. Huo, L. Chong, M. Lee, T. Lee, Y. Duan, W. Wang, O. Donini, P. Cieplak, J. Srinivasan, D. A. Case, and T. E. Cheatham, "Calculating Structures and Free Energies of Complex Molecules: Combining Molecular Mechanics and Continuum Models," *Acc. Chem. Res.*, vol. 33, no. 12, pp. 889–897, Dec. 2000.
- [13] J. Srinivasan, T. E. Cheatham, P. Cieplak, P. A. Kollman, and D. A. Case, "Continuum Solvent Studies of the Stability of DNA, RNA, and PhosphoramidateDNA Helices," *J. Am. Chem. Soc.*, vol. 120, no. 37, pp. 9401–9409, Sep. 1998.
- [14] S. R. Badu, R. Melnik, M. Paliy, S. Prabhakar, A. Sebetci, and B. A. Shapiro, "Modeling of RNA nanotubes using molecular dynamics simulation," *Eur Biophys J*, vol. 43, no. 10–11, pp. 555–564, Nov. 2014. [Online]. Available: <http://link.springer.com/article/10.1007/s00249-014-0985-6>
- [15] M. Paliy, R. Melnik, and B. A. Shapiro, "Molecular dynamics study of the RNA ring nanostructure: a phenomenon of self-stabilization," *Phys. Biol.*, vol. 6, no. 4, p. 046003, Dec. 2009.
- [16] J.-I. Tomizawa, "Control of colE1 plasmid replication: The process of binding of RNA i to the primer transcript," *Cell*, vol. 38, no. 3, pp. 861–870, Oct. 1984.
- [17] J.-I. Tomizawa, "Control of ColE1 plasmid replication: Binding of RNA i to RNA II and inhibition of primer formation," *Cell*, vol. 47, no. 1, pp. 89–97, Oct. 1986.
- [18] A. J. Lee and D. M. Crothers, "The solution structure of an RNA loop-loop complex: the ColE1 inverted loop sequence," *Structure*, vol. 6, no. 8, pp. 993–1007, Aug. 1998.
- [19] V. A. Kuzkin, A. M. Krivtsov, E. A. Podolskaya, and M. L. Kachanov, "Lattice with vacancies: elastic fields and effective properties in frameworks of discrete and continuum models," *Philosophical Magazine*, vol. 96, no. 15, pp. 1538–1555, May 2016.
- [20] W. Lacarbonara, A. Arena, and S. S. Antman, "Flexural vibrations of nonlinearly elastic circular rings," *Meccanica*, vol. 50, no. 3, pp. 689–705, Mar. 2015.
- [21] J. C. Phillips, R. Braun, W. Wang, J. Gumbart, E. Tajkhorshid, E. Villa, C. Chipot, R. D. Skeel, L. Kal, and K. Schulten, "Scalable molecular dynamics with NAMD," *J. Comput. Chem*, vol. 26, no. 16, pp. 1781–1802, 2005.
- [22] MacKerell, D. Bashford, Bellott, Dunbrack, J. D. Evanseck, M. J. Field, S. Fischer, J. Gao, H. Guo, S. Ha, D. Joseph-McCarthy, L. Kuchnir, K. Kuczera, F. T. K. Lau, C. Mattos, S. Michnick, T. Ngo, D. T. Nguyen, B. Prodhom, W. E. Reiher, B. Roux, M. Schlenkrich, J. C. Smith, R. Stote, J. Straub, M. Watanabe, J. Wirkiewicz-Kuczera, D. Yin, and M. Karplus, "All-atom empirical potential for molecular modeling and dynamics studies of proteins," *J. Phys. Chem. B*, vol. 102, no. 18, pp. 3586–3616, Apr. 1998.
- [23] J. F. Marko and S. Cocco, "The micromechanics of dna," *Physics World*, vol. 16, no. 3, p. 37, 2003. [Online]. Available: <http://stacks.iop.org/2058-7058/16/i=3/a=40>

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