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Entropy and Entropic Forces to Model Biological Fluids

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Biological Fluids

- Living cell **Biological fluids (Fig. 1)**
- Polymer: large chains of **1.5 to 7Å** monomers **(Fig. 2)**
  Polymer-Monomer: Protein-Amino Acid, RNA and DNA-Nucleotide, Triglyceride-Fatty Acid
- Polymer configuration: **depends on length, crowding, Temperature and solvent**
- Laboratory to study **exotic emerging physical phenomena**

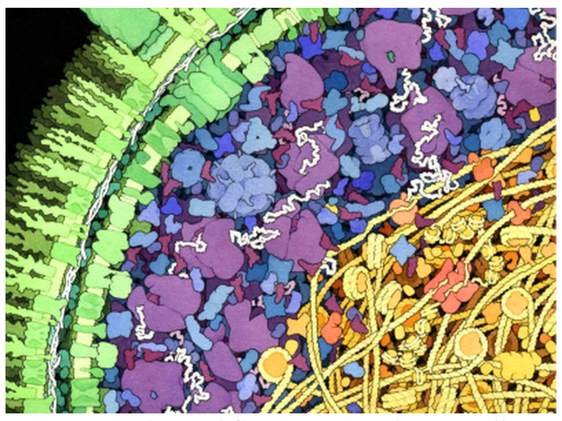

Fig.1. Biological fluid inside a living cell.

Entropy and Complexity

- **Complexity:** many and diverse interacting constituents
- **Crowding:** thousands of distinct interacting polymers
- **Entropy and interactions** drive organization and patterns at different spatial and temporal scales: **Entropic forces and emergent properties,** tendency of a thermodynamic system to maximize its entropy to more probable states

Capturing the essentials: **simple model of a complex system?**

Models: big data era + fundamental principles and understanding = knowledge

The forces

- **Competition of physical and entropic forces (Fig. 3)**
- **Short range resulting repulsive force F1: electromagnetic forces** (electronic clouds superpositions and quantum exclusion principle)
- **Long range resulting attractive F2: entropic forces** (polymer clustering, osmotic pressure). Many body problem highly dependent on temperature.

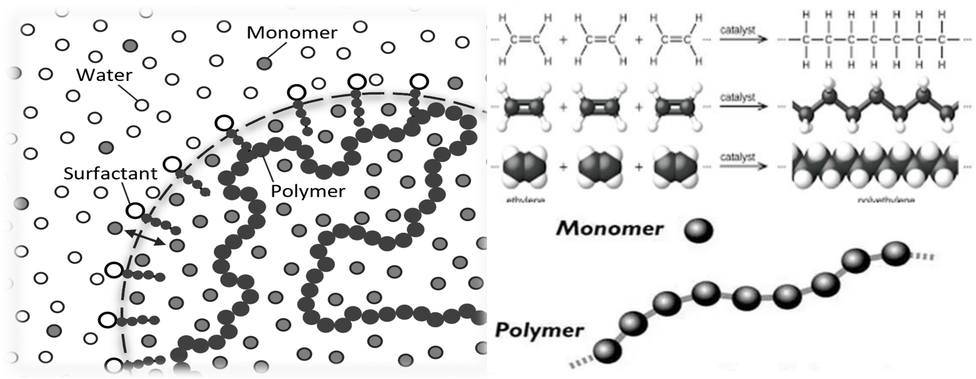

Fig.2. Polymers and monomers constituting the biological fluid inside a living cell.

Model: F1 and **F2** represented by a **Lennard-Jones-like potential (Fig.3):**

$$V_{L-J}(r) = a\varepsilon\left[\left(\frac{\sigma}{r}\right)^{m} - \left(\frac{\sigma}{r}\right)^{n}\right]$$

r: polymer's centre distance to origin reference, ε: equilibrium energy at r_m,
σ: F1=F2, $m >> n$, typically 12 and 6 respectively

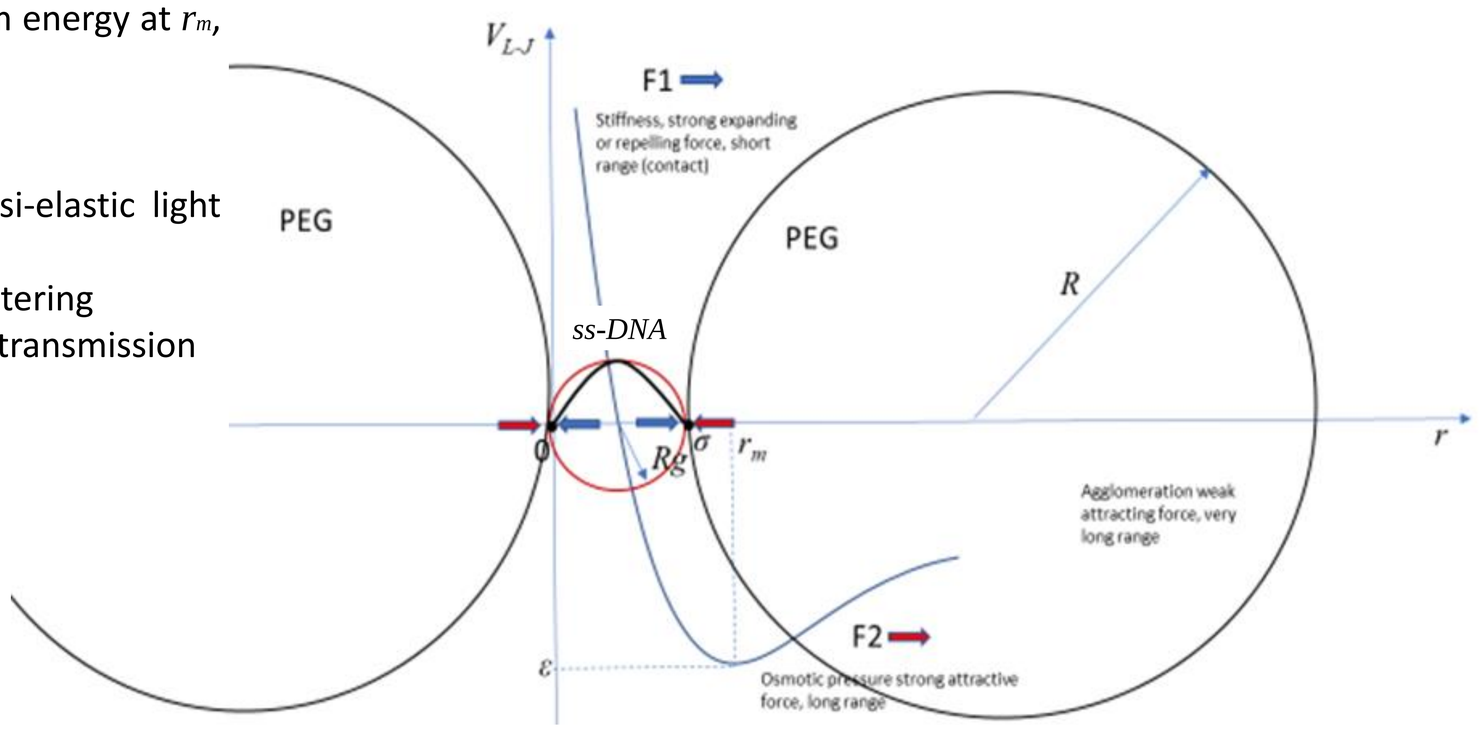

Fig.3. Lennard-Jones like potential $V_{L-J}(r)$, *F1, electromagnetic forces, F2 entropic forces, ss-DNA small polymer between two large polymers PEG with spherical volume of radius R, at r = σ is the minimum of* $V_{L-J}(r)$, *i.e. thermodynamic equilibrium of the system, Rg is the radius of gyration of the small polymer.*

Polymer measures (Fig. 4):

R_h Hydrodynamic Radius from viscosity measures and quasi-elastic light scattering
R_g Radius of Gyration from measures of small angle x-ray scattering
$R_{e\text{-}e}$ end-to-end distance from fluorescent radiation emission transmission
Good solvents $R_h \approx 5/3\ R_g$ and $R_g \approx 1/\sqrt{6}\ R_{e\text{-}e}$
Large polymers: **PEG** 6kg/M Rh ≈ 24Å
Small polymers: ***ss-DNA***, R_g from 20 to 100Å [1,2,3,4].

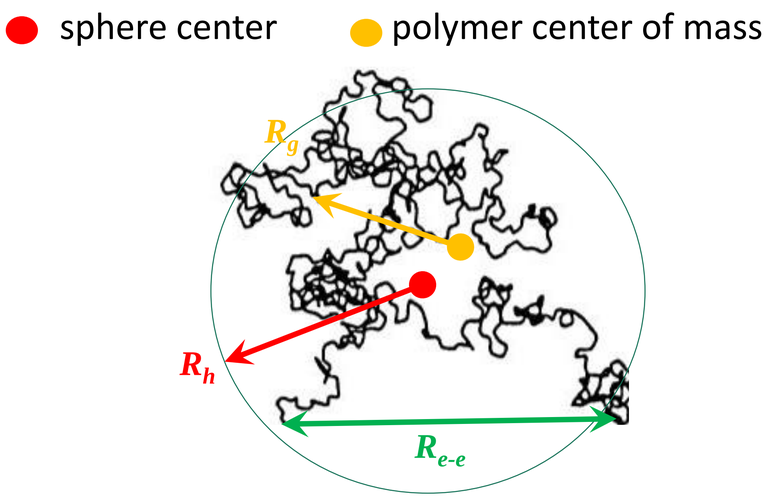

Fig.4. 3D Polymer measures R_h, R_g and $R_{e\text{-}e}$.

Results

The model allows theoretical relations between R_h, R_g and $R_{e\text{-}e}$ at thermal equilibrium for the different conditions that control the forces F1 and F2, allows a better understanding of the polymer configurations and comparisons with experimental data.

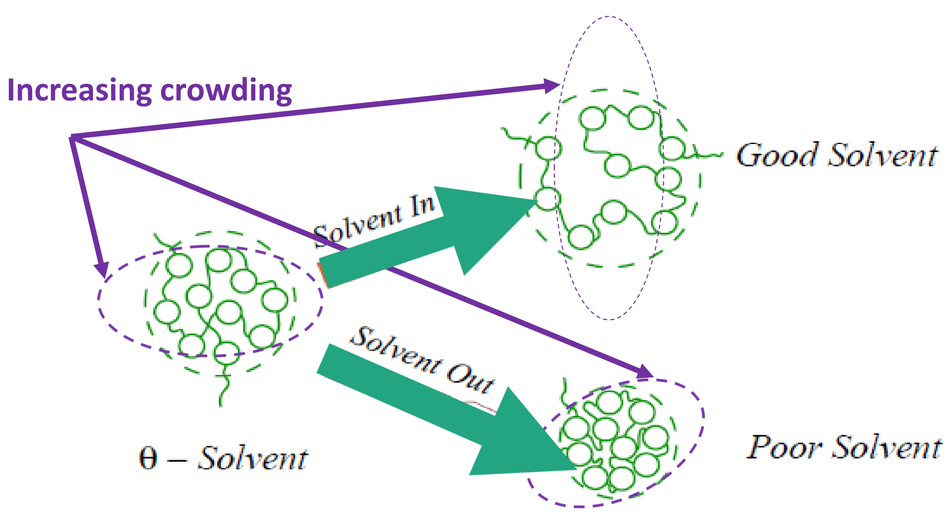

Fig. 5. Polymer configurations depending on solvent and crowding.

Conclusions

Model conducted comparisons between R_h, R_g and $R_{e\text{-}e}$ allow the description of qualitative geometrical changes of the polymer more probable configurations, their sizes and shapes, depending on the relative magnitude and ranges of the forces involved, particularly important for folding and unfolding of small polymers in some conditions and larger polymers in others.

Future work

Quantitative comparison between experimental measures of R_h, R_g and $R_{e\text{-}e}$ for fine variations of solvent, crowding and polymer length to determine the intensities of F1 and F2 at which the polymer may have configuration phase changes: size, shape, symmetry and even dimensionality.

References

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