Lab project M2 PPN

Monday & Tuesday from Oct 2025 to March 2026

Title of the project: Dynamic response of proteins to sub-THz electric-field excitation

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Laboratory / Department / Team: ICB / Nano / Physics Applied to Proteins

Collaborations : Jérémie Margueritat (Institut Lumière Matière, Lyon)

Summary:

Proteins are an important class of nanobioparticles that drives biological processes in living organisms. According to the Anfinsen paradigm, the function of a protein is governed by the unique three-dimensional structure adopted by the protein based on its amino-acid sequence. However, to understand how proteins work, it is also crucial to shed light on their structural behaviour from a dynamic point of view.

Proteins at physiological temperatures exhibit a wide range of intrinsic motions, which span over different spatial and temporal scales, and which are governed by the highly multidimensional free-energy landscape. For instance, conformational transitions of proteins from one substate to another, separated by high free-energy barriers, take place at the microsecond timescale (or even slower) and are associated with the interconversion between open and closed conformations, enzyme catalysis, signal transduction, and/or protein–protein interaction.

Collective motions associated with protein functions can be adequately described by only a few low-frequency vibrations, i.e. acoustical modes in the sub-THz frequency range. **Therefore, there is a considerable interest to measure and establish the role of these acoustical vibrations for the biological function**. Computational methods such as Normal Mode Analysis or Principal Component Analysis applied to proteins atomic coordinates serve as an important tool for the interpretation of spectra investigated by neutron scattering, Raman or Far-infrared spectroscopy. So far, the technique providing the most detailed information about the acoustical modes of proteins is the very recent Extraordinary Acoustic Raman spectroscopy [1]. In this technique, a single protein is trapped in a gold double nanohole and excited by two optical lasers of slightly different wavelengths producing an electric field at low-frequency (< 100 GHz). However, mechanisms of excitation as well as protein response from a structural point of view is not fully explained but is believed to be due to the modulation of the electrostriction force at the trapping site of the molecule.

In this project, the goal is to simulate the structural dynamic response of proteins of different size and shape using pulsed electric field in the frequency range (10-200 GHz) using Molecular Dynamics. Results from simulations will be compared to available experimental data from references [1,2] and will help the interpretation of experimental spectra. In total, 5 proteins will be tested (Conalbumin, Cyclo-oxygenase, Aprotinin, Carbonic Anhydrase, Streptavidin). The influence of the gold substrate will also be tested computationally.

[1] Wheaton, S., Gelfand, R. & Gordon, R. Probing the Raman-active acoustic vibrations of nanoparticles with extraordinary spectral resolution. *Nature Photon.* 9, 68–72 (2015). https://doi.org/10.1038/nphoton.2014.283

[2] DeWolf, T. & Gordon, R. Theory of Acoustic Raman Modes in Proteins. Phys. Rev. Lett. 117, 138101 (2016). https://doi.org/10.1103/PhysRevLett.117.138101

Type of project (theory / experiment): theory / computation

Required skills: Proteins, Molecular Dynamics, Programming (Python)