Master 2
INTERNSHIP PROPOSAL

Laboratory name: Laboratory Gulliver, ESPCI
CNRS identification code: UMR 7083 & UMR 7241
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Internship location: Gulliver lab, ESPCI Paris & CIRB, Collège de France, Paris
Thesis possibility after internship: YES

Designing Catalysts from the Bottom-up

Enzymes are unsurpassed catalysts in Nature - they catalyze a wide range of biochemical reactions in an energy-efficient and environmentally friendly manner. There is a huge interest and activity in designing biocatalysts for non-biological reactions, ranging in impact from detergents to recycling and gene therapy. However, we are far from reaching the versatility and success of natural enzymes in biological reactions. We believe that an important limitation comes from our lack of understanding of the fundamental constraints on enzymes' efficiency.

Catalysis is well understood in principle but we do not have a theoretical framework for building catalysts from scratch. The dominant design rule is Pauling's principle, according to which catalysts should stabilize transition states. This has been the guiding principle for selecting catalytic antibodies (currently the most successful mimics of enzymes) and behind the computational design of new enzymes (e.g. Rosetta). In any case the artificially produced enzymes fall short of achievements of natural ones. The source of the limitation is not completely clear, apart from the fact that Pauling's principle focuses on thermodynamical requirements for the catalytic step while there are additional constraints coming from kinetics, geometry and physics that need to be considered when regarding full catalytic cycles.

Over the past few years we have been setting theoretical foundations for a more general theoretical framework that can be directly applied to the experimental design of artificial catalysts [1-3]. We focused on a simple reaction, bond cleavage, in the context of a simple molecule, a dimer, and identified what is the minimal catalyst design that can catalyze the reaction. The goal of this internship is to further explore the catalyst's parameter space using theory and coarse-grained computer simulations.

We are looking for a candidate with a strong background in statistical physics and an interest for interdisciplinary subjects. The project combines theoretical work together with computational simulations and data analysis. The internship can be followed by a PhD thesis.

[1] M. Muñoz Basagoiti, O. Rivoire and Z. Zeravcic (2021), Physics and Evolution of Catalysts, APS March Meeting
[2] O. Rivoire (2020). Geometry and Flexibility of Optimal Catalysts in a Minimal Elastic Model. JPC B, 124(5)
[3] Z. Zeravcic, M. P. Brenner (2017). Spontaneous Emergence of Catalytic Cycles with Colloidal Spheres, PNAS 114