

THERMODYNAMICS MODELLING OF POWER PRODUCTION IN LIVING SYSTEMS: A BIOMIMETIC MODEL OF OPTIMISATION CONSTRAINED BY RESOURCE MANAGEMENT

— LIED —

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To know more about it, see

- Herbert *et al.* Thermodynamics of Animal Locomotion. *Phys. Rev. Letters* (2020):
- Goupil *et al.* Thermodynamics of metabolic energy conversion under muscle load, *New J. Phys.*, (2019)
- Blot, Herbert, Goupil, From molecular ratchets to energy converters: a unified thermodynamic description of molecular motors (in preparation)



Figure 1: Two morphotypes of the same species, *Astyanax mexicanus*. Left is the slow, blind and depigmented cave morphotype, right is the fast surface morphotype. From our description, both locomotion type can be recovered by varying the number of standard muscle fibers N .

Research environment Research will be conducted at the LIED, an interdisciplinary lab gathering a broad spectrum of disciplines, located at *Université Paris Cité* on the *Rive Gauche campus*.

Profile sought Interns would work in close interaction with a team of physicists and biologists. An interest in the physics of living systems, and familiarity with common programming languages such as Python, are essential.

Continuation to a PhD is possible, but not yet funded. Joint application to grad school funding possible.

Power production mechanism , eg dedicated to locomotion, is a general and vital process based in the animal world on the degradation of ATP molecules during the Krebs cycle. However, this common process, far from freezing the modalities of use and power production of living systems, adapts to the specific environmental constraints encountered by each population. More specifically, we are interested, in a biomimetic approach, in the **adaptive optimisation of energy conversion systems according to the constraints imposed on access to resources**.

To this end, we developed a theoretical and experimental approach, deriving the well-known Onsager formalism of **non-equilibrium thermodynamics** to living systems and relying on the description of **biological mechanisms of metabolism**, and in particular oxygen consumption. This allows us to reconstruct the energy flows through the organism and to characterise it quantitatively using generic parameters allowing inter-individual comparison.

Master Internship. In previous work, we have shown that it is possible to describe the different gaits of an organism (walk, trot and gallop in the case of the horse) with a single

degree of freedom, the number of standard muscle fibers involved in locomotion. In parallel, we have recently extended this framework down to the molecular scale: a molecular motor (myosin, kinesin, dynein) obeys the same boundary energy balance as a thermoelectric generator, and is characterised by a few generic parameters (isometric force f_0 , conversion coefficient α , intrinsic resistance R , basal consumption B) that can be extracted from force–velocity data.

Depending on the candidate’s profile, the internship can follow **one of two tracks**:

- **Experimental track – *A. mexicanus* thermodynamic phenotyping.** Experiments are carried out in the laboratory on the two sub-populations of *A. mexicanus*, a small piranha-like fish with two highly differentiated morphotypes, adapted to a very poor (cave) or very rich (surface) nutrient environment; the cave morphotype has evolved into a non-pathological form of type 2 diabetes. Using our swimming tube coupled to O_2 sensors, the student will measure oxygen consumption as a function of swimming speed and effort duration for both populations. The data will be analysed within our thermodynamic model to extract and compare the characteristic parameters (conversion coefficient, dissipation, basal power, number of recruited fibers) of the two morphotypes, and to identify which of them carry the adaptation to resource scarcity.
- **Theoretical track – from molecular motors to muscle respiration.** Starting from the thermodynamic description of the molecular motor, the student will build a model of the muscle as an assembly (series/parallel) of motors and insert the **mitochondria** as the ATP-regenerating stage, coupling ATP hydrolysis to oxidative phosphorylation. The goal is to express the energy fluxes of the muscle in terms of **oxygen consumption**, which is directly accessible experimentally (respirometry), and thus to connect microscopic parameters to whole-organism measurements. Model predictions will be confronted with literature data and with our fish experiments.