Ingénierie des Matériaux Polymères — Université Jean Monnet Saint-Étienne — Laboratoire Hubert Curien (UMR • CNRS • 5516 • Saint-Etienne)

Ph.D Thesis offer

Magnetic Hyperthermia of Soft Materials: A Physics-Informed Machine Learning Approach

Context: Magnetic Hyperthermia (MH), the process of heating materials via magnetic nanoparticles exposed to a high-frequency magnetic field, holds transformative potential in diverse fields. Widely used in biomedical engineering, MH is among the most promising cancer treatment methods, particularly when combined with radiotherapy, chemotherapy, or immunotherapy (**Fig. 1a**). Beyond medicine, MH is emerging as a groundbreaking tool in materials science and chemistry, enabling polymer repair and novel high-temperature synthesis pathways. However, MH development is hampered by our limited understanding of the multiphysics nature of heat generation, namely, the impact of the host material and the related mechanical friction.

Objective: The objective of this Ph.D thesis is to switch from the usual multi-parameter experimental approach, where the specific heat generated by the nanoparticles is governed by their intrinsic magnetic properties and the viscoelastic behavior of the host material [1, 2], to a *physics-informed machine learning* [3] (PiML) point of view. PiML aims to embed theoretical knowledge (typically in the form of differential equations) into the learning process. This allows to predict consistent solutions even when training data is scarce. The relevant physics involved in MH concern (i) heat equation, (ii) phase transitions (e.g., melting) and (iii) frictional models. Leveraging this physical prior as well as a series of temperature measurements performed in various polymer-based host materials (**Fig. 1b**), the Ph.D candidate will design a new PiML approach to model the MH process (**Fig. 1c**). Experiments regarding the structural evolution of the nanoparticles along with magnetic irradiation will enable to restrict the variables space.

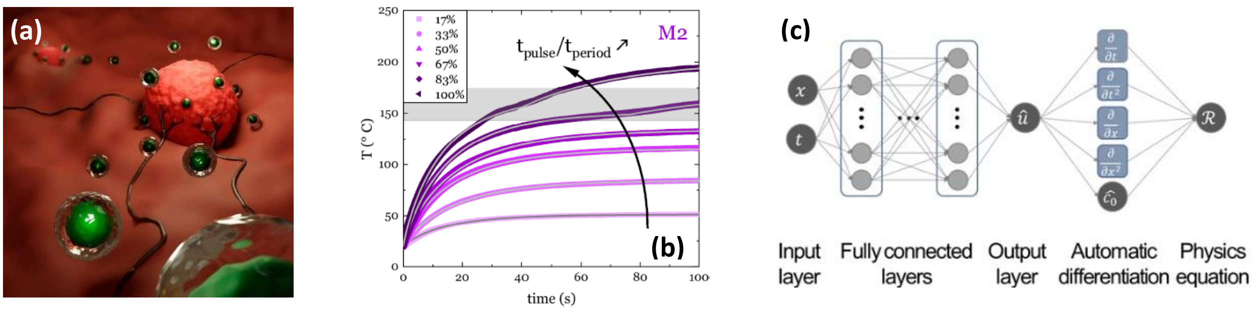

Figure 1: a) Artist view of magnetic nanoparticles travelling to a tumoral cell prior their activation with an oscillatory magnetic field. b) Temperature evolution during a MH experiment for various magnetic pulse duration [2]. c) Schematic view of a physic-informed neural network.

Details: The present offer emerges from a collaboration between the IMP lab and the Inria team MALICE – a part of the Hubert Curien lab – in the framework of the upcoming Graduate School of Engineering including the University Jean Monnet, at Saint-Etienne, France. Both laboratories are located on the same campus "Manufactures" and benefit from brand new buildings.

Starting date: September-October 2025. Net monthly salary: 1.8 k€. Application deadline: March 15th, 2025.

Profile sought:

Master (or equivalent) in physics or materials science with an appetite for AI and machine learning.

Master (or equivalent) in applied mathematics or computer science who wishes to engage with physical problems.

Contact :

Guilhem Baeza (guilhem.baeza@univ-st-etienne.fr), IMP lab (LINK)

Eduardo Brandão (eduardo.brandao@univ-st-etienne.fr), Hubert Curien lab (LINK)

References:

[1] Pommella et al., *ACS Nano* **2023**, 17, 17, 17394–17404

[2] Griffiths et al., *ACS Appl. Polym. Mater.* **2024**, 6, 23, 14084–14094

[3] Karniadakis, et al., *Nature Reviews Physics* **2021**, 422-440.