

French Polytech network form for PhD Research Grants from the China Scholarship Council

This document describes one of the PhD subjects proposed by the French Polytech network. The network is composed of engineering schools/universities. The document also provides information about the supervisor.

Supervisor information	
Family name	KUZHIR
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Lab name	Institute of Physics of Nice (INPHYNI)
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Polytech name	Polytech Nice-Sophia (PNS)
University name	University Côte d’Azur
Country	France

PhD information	
Title	Dynamics and Emerging Functionalities of Self-Assembled Magnetic Nanovesicles in Confined Environments
Main topics regards to CSC list (3 topics at maximum)	IV.5. Intelligent materials and rare earth materials; IV.1. Nanotechnology and Nanotechnique

Required skills in science and engineering	Basic knowledge in experimental physics and/or physical engineering and/or computational physics
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Subject description (two pages maximum including biblio)

Magnetic nanovesicles are emerging multifunctional nano-objects capable of combining magnetic responsiveness with molecular encapsulation, controlled release and mechanical adaptability. Under external magnetic fields, these soft magnetic objects can reversibly self-assemble into elongated chains, clusters or more complex dynamic architectures whose collective behavior is fundamentally different from that of isolated nanoparticles [1]. Unlike rigid magnetic micro-objects, these field-induced assemblies continuously reorganize under the combined action of magnetic interactions, hydrodynamic forces and thermal fluctuations, making them an attractive model system for investigating non-equilibrium soft matter [2].

Recent advances have demonstrated that magnetic self-assemblies can be transported through confined microfluidic environments using time-dependent magnetic fields [3]. However, despite the rapid development of this field, the physical mechanisms governing their motion inside confined geometries remain largely unexplored.

The proposed PhD project aims at establishing the fundamental physical principles governing the transport of magnetically self-assembled nanovesicles in confined fluidic channels. Rather than considering individual magnetic particles, the project will investigate dynamic self-assemblies formed in situ under external magnetic fields. Depending on the applied magnetic field configuration, these assemblies may exhibit translational motion, rotational dynamics, shape fluctuations or reversible structural transitions. Understanding how these collective states emerge from the competition between magnetic, hydrodynamic and thermal forces constitutes the central scientific objective of the project. Particular attention will be devoted to hydrodynamic interactions in confinement. The project will investigate how the solid walls of the microchannels influence transport efficiency, collective diffusion and structural reorganization. Experimental observations performed in microchannels will be complemented, whenever possible, by theoretical modelling based on slender-body approximations.

Beyond their mechanical transport, magnetic nanovesicles offer the possibility of coupling locomotion with additional physical functionalities. One research direction will investigate molecular diffusion from nanovesicles subjected to high-frequency alternating magnetic fields. Magnetic heating generated by Néel and Brownian relaxation mechanisms may locally modify membrane permeability, allowing controlled thermally activated release of encapsulated molecules [4]. The project will seek to establish quantitative relationships between magnetic field parameters, local temperature elevation, membrane transport properties and molecular diffusion in confined environments. Another research direction concerns the electromechanical response of magnetically induced self-assemblies incorporating piezoelectric or magnetostrictive components. Periodic magnetic deformation of such assemblies may generate transient electric fields through magneto-mechanical coupling [5]. The resulting electrical stimulation could influence ionic transport, electrokinetic phenomena or promote the formation of

reactive oxygen species in aqueous media. The underlying mechanisms remain largely unexplored and constitute a challenging problem at the interface between soft condensed matter physics, electrohydrodynamics and colloidal science.

The PhD fellow will perform a systematic experimental investigation of the dynamic behavior of magnetic nanovesicle assemblies inside micro-channels under static, rotating and alternating magnetic fields. Quantitative image analysis will provide information on assembly morphology, transport velocity, rotational dynamics, collective diffusion and structural stability. Depending on the candidate's profile, these experiments will be complemented by theoretical modelling and numerical simulations describing the coupled magnetic, hydrodynamic and Brownian interactions governing the observed dynamics.

Overall, the project aims to establish a comprehensive physical framework describing the behavior of magnetically driven soft self-assemblies under confinement. The expected outcomes include a deeper understanding of field-induced collective transport, non-equilibrium self-organization, confined hydrodynamics and coupled transport phenomena involving heat, mass and electric fields. These fundamental results will provide a scientific basis for future developments in magnetically controlled soft matter, targeted molecular transport and multifunctional nanomaterials.

In general, the PhD project is inscribed into a large research topic of the hosting team related to hydrodynamics and phase separation of magnetic nano-colloids, in which two assistant professors, two post-doc fellows and two PhD students are involved. The hosting team from Institute of Physics of Nice has a broad experience in physico-chemistry, physics and applications of magnetic nanoparticle colloids. In particular, the PhD director, Dr. Pavel Kuzhir is the head of the hosting team and is an expert in field-induced self-assembly (aggregation) of magnetic nanoparticles and microfluidic flows of magnetic dispersions (both from experimental and theoretical perspectives) [6,7], while other team members are specialists in synthesis, surface and colloidal chemistry of magnetic nanoparticles [8,9]. The team has all the necessary equipment to conduct the experimental part of the PhD project (materials, electromagnets, amplifiers, characterization tools – dynamic light scattering, zeta-sizer, magnetometer, ...) and a free access to the clean room at INPHYNI (for microfluidic fabrication) and the university technological platforms (TEM, SEM, 3D-printing, ...). The team has a very positive experience on hosting CSC funded Chinese fellows (2 defended PhD + 2 current PhD).

The PhD fellow will benefit from the scientific environment and research web of the team. The team is engaged to send the fellow to at least one international and possibly several national scientific conferences or meetings. Several scientific publications will be prepared for submission to highly ranked international journals.

[1] Salatin et al. Expert Opinion on Drug Delivery, 21(4), 521-535 (2024).

[2] Garcia-Jimeno, et al. Nanoscale, 9(39), 15131-15143 (2017).

[3] Pamme, N. Lab on a Chip, 6(1), 24-38 (2005).

[4] Hardiansyah, et al. Nanoscale research letters, 12(1), 355 (2017).

[5] Ferson, N. D., et al. IEEE Trans ultrasonics, ferroelectrics, frequency control, 68(2), 229-241 (2020).

[6] Kuzhir, P., et al. J. Magn. Magn. Mater. 431, 84-90 (2017).

[7] Orlandi, G., Kuzhir, P., et al. Phys. Rev. E, 93(6), 062604 (2016).

[8] Marins, J. A., ... & Kuzhir, P. ACS Appl. Nano Mater., 1(12), 6760-6772 (2018).

[9] Queiros Campos, ..., Godeau, G., & Kuzhir, P. Langmuir, 37(49), 14345-14359 (2021).