SOCIETE FRANÇAISE DE THERMIQUE

Groupe thématique « modes de transfert »

Journée thématique organisée par :
Cédric BLANCHARD (CEMHTI – Orléans)
Franck ENGUEHARD (Institut Pprime – Poitiers)

VENDREDI 3 OCTOBRE 2025

Accueil à partir de 9h00 à
FIAP, 30 rue Cabanis, Paris 14 - Métro Glacière

Diffusion collective de la lumière par des nanoparticules résonantes ou par des dispersions de particules dont la taille caractéristique est de l'ordre de grandeur de la longueur d'onde

Périmètre scientifique de la journée :

Cette journée thématique vise à réunir des chercheurs issus de différentes communautés scientifiques du cadre européen, qui appréhendent l'interaction lumière/matière avec des visions et des perspectives variées, mais qui ont pour dénominateur commun de travailler sur la simulation numérique des ondes électromagnétiques en milieux particulaires complexes (le mot « particulaire » étant entendu au sens large : inclusions sphériques, fibres, etc.). Soutenue par le Groupement de Recherche TAMARYS du CNRS (https://gdr-tamarys.cnrs.fr/) et par la Société Française de Thermique (https://www.sft.asso.fr/), cette journée sera l'occasion de faire le point sur les dernières avancées dans différents domaines et les orientations qui y sont prises. Elle permettra également de stimuler les discussions sur les problématiques rencontrées et les stratégies qui sont déployées pour les traiter, et par là-même de créer un espace d'échange dans le but d'élargir l'angle d'attaque aux verrous scientifiques.

Du fait de la présence d'intervenants internationaux, les échanges pendant cette journée auront lieu ***en langue anglaise.***

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PROGRAMME

9h00-9h20 : welcome of participants

9h20-9h30 : introduction of the day (Cédric Blanchard and Franck Enguehard)

9h30-10h10 : **Alejandro Manjavacas,** CSIC, Nanophotonics Theory Group, Madrid, Spain : « Modelling the response of periodic arrays of metallic nanostructures »

10h10-10h50 : **Romain Pierrat,** Institut Langevin Ondes et Images, Paris, France : « Effect of structural correlations on light propagation in disordered media »

10h50-11h10 : coffee break

11h10-11h50 : **Maxim Yurkin,** CORIA, Rouen, France : « The discrete dipole approximation for scattering simulations of subwavelength particles »

11h50-12h30 : **Philippe Lalanne,** Institut d'Optique Graduate School, Talence, France : « Modeling disordered metasurfaces »

12h30-14h00 : lunch

14h00-14h40 : **Artur L. Gower,** University of Sheffield, Dynamics Research Group, Sheffield, UK : « How coherent waves see particles : boundary conditions and measuring particle sizes »

14h40-15h20 : **Jérémi Dauchet,** Institut Pascal, Aubière, France : « Electromagnetism problems faced by the photo-processes axis of the CNRS research federation FédEsol on solar energy »

15h20-15h40 : coffee break

15h40-16h20 : **Jérôme Yon,** CORIA, Rouen, France : « A strategy for modeling the radiative properties of nanoparticle aggregates »

16h20-16h30 : summary of the day (Cédric Blanchard and Franck Enguehard)

The abstracts of the talks are given in the following pages.

Modelling the Response of Periodic Arrays of Metallic Nanostructures

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Two-dimensional periodic arrays of metallic nanostructures can support collective optical modes known as lattice resonances. These excitations emerge at wavelengths determined by the periodicity of the array, leading to exceptionally strong and spectrally narrow optical responses. Owing to these remarkable properties, periodic arrays are widely used in applications such as ultrasensitive biosensing, nanoscale light emission, and color printing.

In this talk, we will discuss recent theoretical advances in the theoretical modelling of lattice resonances. Specifically, we will examine how the interplay between the response of individual array constituents and their collective interactions determines the ultimate limits of near-field enhancement and the quality factor of a lattice resonance. We will also explore the response of arrays with multi-particle unit cells through an analytical approach based on hybridization theory, which provides a simple and efficient framework for designing periodic arrays with tailored optical properties. Additionally, we will investigate how the characteristics of the excitation source influence the optical response of the array. Finally, we will analyze different array geometries that support lattice resonances with extraordinary properties, including perfect circular dichroism and perfect absorption.

Effect of structural correlations on light propagation in disordered media

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In this presentation, we will start with some generalities about light propagation in correlated disordered media. Then we will illustrate the presentation with some surprising results concerning the transparency, absorption and even localization properties of such media. In particular, we will look at the special case of hyperuniform materials, where correlation effects are very important.

The discrete dipole approximation for scattering simulations of subwavelength particles

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Electromagnetic scattering is widely used in remote sensing of various objects ranging from metal nanoparticles and macromolecules to atmospheric aerosols and interstellar dust. All these applications require accurate simulations, which are not trivial for particles of arbitrary shape and internal structure. The discrete dipole approximation (DDA) is one of the versatile methods to handle such problems.

This talk will begin with an introduction to the DDA, covering both the basic underlying physical picture and a rigorous derivation starting from the integral form of Maxwell's equation for the electric field. This derivation emphasizes that the DDA is a numerically exact method and a special case of volume-discretization method of moments. Notably, the DDA is applicable to almost any electromagnetic problem involving non-magnetic particles. It can handle arbitrary shaped beams, particles in complex environments (e.g., on a multi-layered substrate), and simulate a broad range of quasi-classical electromagnetic phenomena (such as emission enhancement, near-field radiative heat transfer, and electron energy-loss spectroscopy).

Although the DDA applies to a wide range of particle sizes, the talk will focus specifically on subwavelength ones, discussing the corresponding computational aspects and modern DDA formulations. The latter are implemented in open-source DDA codes, such as ADDA, which largely explains the method's popularity. Finally, I will highlight current capabilities and limitations (open questions) of the DDA in application to subwavelength systems.

Modeling disordered metasurfaces

M. Chen, T. Wu and P. Lalanne
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Abstract: Disordered metasurfaces, comprising non-periodic arrangements of meta-atoms, have recently emerged as a versatile platform for harnessing both near- and far-field scattered light in a wide range of applications [Adv. Opt. Photon. **17**, 45-112 (2025)]. We review our current effort to model the resonance of random collections of resonators with various theories, including quasinormal modes expansion and multiple scattering.

Quantitatively predicting the scattering properties of disordered metasurfaces is challenging as it requires advanced knowledge of the nanoscale resonances, mesoscale interferences and macroscale light transport to compute the bidirectional reflectance distribution function (BRDF).

Despite this difficulty, we have recently succeeded in designing the very first simulation tool to quantitatively predict the appearance of disordered metasurfaces [2-3]. The modelling platform may find use in several branches of visual arts, to predict the appearance of augmented reality devices using metasurfaces, design unusual effects for counterfeiting applications…

At the conference, we will review our recent efforts to model and understand the optical properties of disordered metasurfaces with various approaches, including the independent scattering approximation [1], refined models including multiple scattering [2-3], and quasinormal mode analysis [4-5].

Acknowledgements

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References

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3. A. Agreda, T. Wu, A. Hereu, M. Treguer-Delapierre, G.L. Drisko, K. Vynck, P. Lalanne, "Tailoring Iridescent Visual Appearance with Disordered Resonant Metasurfaces," ACS Nano **17**, 6362-72 (2023).
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5. T. Wu and P. Lalanne, "Dissipative Coupling in Photonic and Plasmonic Resonators", Advanced Photonics (2025).

How Coherent Waves See Particles: Boundary Conditions and Measuring Particle Sizes

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Disordered particulate materials are everywhere - from the food we eat to pharmaceuticals, battery materials, and catalysts. Accurately measuring particle size distributions in these dense systems is critical for improving industrial control and reducing waste. One promising approach is to use waves - acoustic or electromagnetic - to probe these materials. However, a key challenge lies in how we handle the boundary conditions when modeling wave interactions in such complex random media. In this talk, I will explain how to deduce the boundary conditions from first principles that led us to accurate wave-based measurements. I'll focus on our results using acoustic waves, showing how we can now extract particle size distributions in dense particulate systems.

Electromagnetism problems faced by the photo-processes axis of the CNRS research federation FédEsol on solar energy

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The photo-processes axis of the CNRS research federation FédEsol (https://www.fedesol.cnrs.fr/federation-energie-solaire/) brings together researchers from different scientific communities to work on solar applications in which ultraviolet–visible radiation is used to implement photoreactions leading to the direct production of molecules of interest, or the degradation of residual pollutants. This research tackles two types of interaction problems between electromagnetic radiation and complex catalytic materials: i) assessing the absorption and scattering properties of particles, either with low refractive index contrasts in the case of photosynthetic micro-organisms, or high contrasts in the case of semiconductor particles for artificial photosynthesis and decontamination, but always with complex shapes, ii) assessing the local absorption rate of radiation within nanostructured photoelectrodes made of semiconductor, in order to evaluate the photogeneration rate of charge carriers. The presentation will take up the results and discussions of the last two FédESol workshops and will be divided into 3 parts:

- three representative configurations with which we are confronted will be presented (to serve as a basis for discussions),
- the methods we have used to date and those we are developing using a statistical approach solved by the Monte Carlo method will be presented,
- the methods we are using to validate these modeling results using three-dimensional quantitative spectrophotometry will be described, and the pitfalls to be avoided in this type of validation will be highlighted.

A strategy for modeling the radiative properties of nanoparticle aggregates

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To improve optical sensors, to enhance the accuracy of climate models and access to a better optical characterization of nanoparticles synthesized in flames, such as soot or metal oxides, it is crucial to refine the modeling of the radiative properties of those aerosol particles. Mie theory is still frequently used for non-spherical particles, which can lead to significant errors. Over 30 years ago, asymptotic theories valid for subwavelength nanoparticles were developed to account for the specific characteristics of fractal aggregates (Rayleigh-Debye-Gans Theory for Fractal Aggregates). Although this theory is not yet widely adopted in the atmospheric community, it is still utilized by the combustion community.

Concurrently, the development of T-matrix methods and the Discrete Dipole Approximation (DDA) has enabled the precise determination of particle absorption and scattering cross-sections, even for complex-shaped particles. While these approaches hold great potential, their computational demands are too high for practical use in climate models or inversion tools. Some groups have attempted to build databases [1], but the vast number of parameters—such as the distribution of primary spheres, overlapping, necking, aggregate size, fractal dimension, local compactness, optical index, and coating—makes it impractical to cover all possible configurations.

For this reason, our long-standing strategy has been to introduce analytical correction factors to the RDG-FA theory through exact computations based on DDA. These corrections enhance the predictive capabilities of the theory while retaining its analytical simplicity. This approach has been applied to evaluate the impact of primary sphere size [2], polydispersity [3], overlapping and necking [4], coating [5], and optical index [6]. A brief review of these results will be presented.

To work with realistic aggregates, it was necessary to improve the virtual conception of particles. Therefore, we developed an aggregation code, which will be presented [7], [8], [9], to enhance the modeling of soot particles. However, it remained challenging to develop corrections for the RDG-FA theory without a better understanding of the physical phenomena not well captured by this asymptotic theory. Recently, we made significant progress by studying the internal electric field through phasor analysis [10]. This approach allowed us to identify the main factors influencing the errors in RDG-FA, such as the internal trapping of light [11] and how internal coupling affects the angular dependence of scattering [12]. This presentation will outline the methodology used and the results obtained.

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