Master in Chemistry

"Light, molecules, matter" course

Graduate Programme

Lumomat

Syllabus

Master 1 degree

Nantes Université

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INTRO

Our Light, Molecule, Matter (Lumomat) programme is accredited as a Master's and Doctorate programme (CMD) by Nantes University. It is an integrated programme that offers excellent opportunities for those wishing to pursue a career in academic research or in corporate research and development. This label, supported by the French National Research Agency (ANR), certifies that the programme draws on the expertise of four internationally recognised laboratories:

Lumomat is part of the high-potential photoscience industry, particularly photochemistry, which has applications in various key fields such as energy, health, the environment and information storage.

The synergy of skills within the Lumomat team offers you the opportunity to develop unique expertise in the field of molecules and molecular materials. Teaching is based on a balance between lectures, practical work, tutorials and immersion in the research laboratory. Workshops and projects involving close interaction with academic and industrial players allow you to tailor your course to your career goals.
The workshops and practical work are supported by state-of-the-art equipment available within the platforms and partner laboratories of the LUMOMAT University Research School (EUR), which backs this programme. The complementary areas of expertise of these contributors enable you to tackle the entire molecular architecture development chain: design, modelling, synthesis and application.

MASTER'S PROGRAMME COORDINATORS

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TEACHING LOCATION

UFR Sciences and Technology
Lombarderie Campus
2, rue de la Houssinière
PO Box 92208
44322 Nantes

SKILLS DEVELOPED

Upon completion of the master's programme, you will have:

- Developed knowledge of the business world and an awareness of entrepreneurship,
- Gained project management experience.

You will be able to:

- Use molecular and supramolecular engineering techniques to synthesise functional materials,
- Propose eco-friendly synthesis methods for these innovative materials,
- Choose the right characterisation techniques and theoretical models to optimise the properties of functional materials,
- Share knowledge about organic materials, their market opportunities and applications,
- Supervise and lead R&D projects in the field of organic materials (molecular photonics and electronics), in the environment, pollution and health
- Propose a series of characterisation strategies to establish links between the structure and electronic and photonic properties of materials.

CAREER OPPORTUNITIES

With a Master's degree in Chemistry from LUMOMAT, you will be able to work as an engineer (synthesis, analysis, instrument management) and eventually take on management roles in companies involved in R&D and innovative project management.

You will also be able to enter public research at the research engineer level through competitive examinations in major public research organisations (universities, CNRS, INRA, INSERM, etc.) or prepare a PhD thesis in France or abroad with easy access to thesis funding (e.g. CIFRE-type grants in conjunction with a company, funding via calls for projects from EUR LUMOMAT and its network).

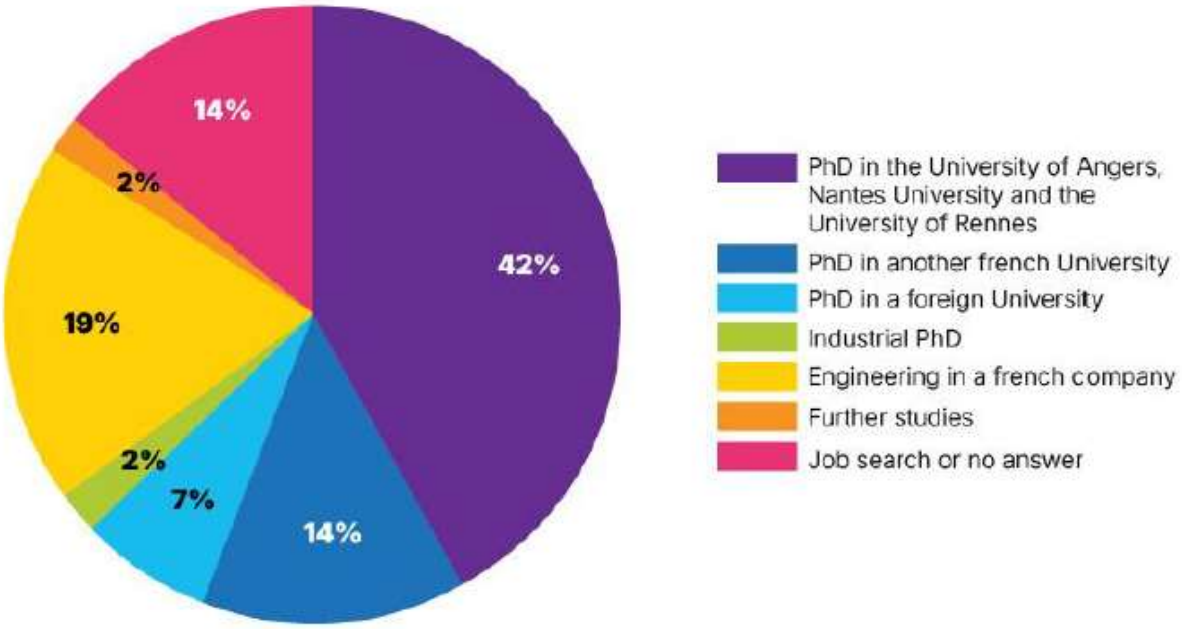
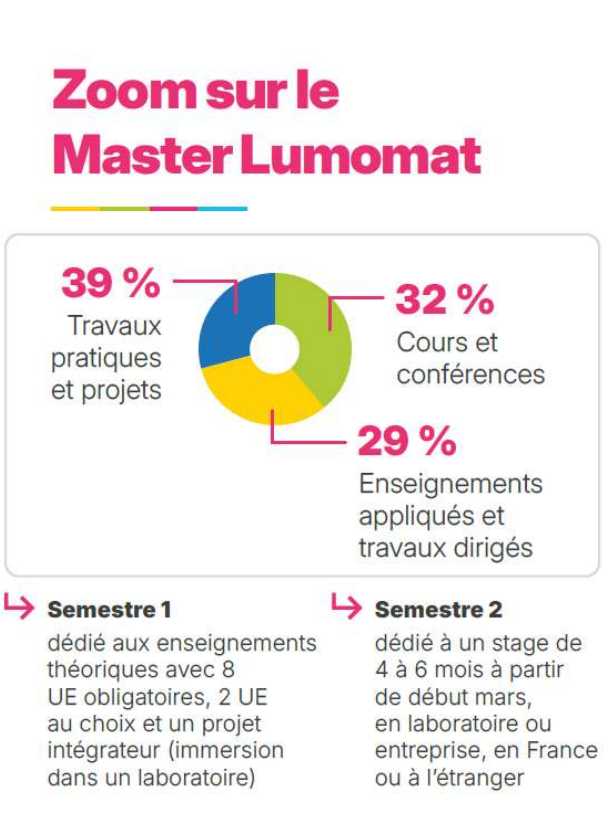


Figure 29. Diagram showing the professional integration of Master students from the 2020-2024 cohorts

PROGRAMME STRUCTURE



JOIN THE LUMOMAT MASTER'S PROGRAMME

Scholarship

A welcome grant of €1,500 is awarded to international students who enrol on our programme. They can also apply for the G. Eiffel Excellence Scholarship and any scholarships offered by their embassy.
Students who wish to do an internship abroad can also receive mobility assistance in the form of a monthly allowance of €500 to €700 (subject to eligibility).

How to apply

The prerequisites and various admission procedures are detailed on the programme page of the Nantes University website:

Block 1: Core curriculum for the Master's in Chemistry

TEACHING UNIT (TU): MOLECULAR SYNTHESIS AND MODELLING (3 ECTS)

Concepts of solvents and reactivity

Related TE: Molecular synthesis and modelling		
Number of hours: 8	Number of ECTS: 0.75	
Year/semester: M1/S1	Language of instruction: mixed French/English	
Lecturer:	Clémence Quéffelec Pierrick Nun	
Objectives	• Learn about the main solvents and their reactivity • Distinguish between different types of bonds and anticipate their reactivity • Describe a reaction mechanism	
Topics covered:	*1. Solvents:* - Main solvents, structure (and acronym) - Physicochemical properties (polarity, dielectric constant, acidity, basicity, etc.) - Choosing a solvent based on its usefulness (solubilisation, heating, environmental impact, etc.) *2. Reactivity:* - Electrophilicity/nucleophilicity - Reactivity of chemical bonds - Valence theory *vs.* OM theory - Writing a reaction mechanism *3. Bonds (distance learning):* - Main chemical bonds - Polarity/Polarisability	
Teaching methods:	Distance and face-to-face teaching, exercises in groups of 4-5 students.	
Bibliography:	Online documentation on MADOC	

Coordination chemistry

Related course unit: Molecular synthesis and modelling		
Number of hours: 8	Number of ECTS credits: 0.75	
Year/semester: M1/S1	Language of instruction: French	
Lecturer:	Rémi Dessapt	
Objectives	• Predict the stability and reactivity of a coordination complex • Understand bonding models (crystalline field/molecular orbitals) and their limitations	
Topics covered:	This course covers the molecular aspects of inorganic chemistry. The foundations are laid with a presentation of the structure and reactivity of transition metal complexes. 1. Review - Coordination complexes (Types of ligands / Complex geometry) 2. Review - Use of a crystal field bonding model 3. Stability of transition metal complexes 4. Introduction to the reactivity of transition metal complexes.	

Teaching methods:	Lectures and tutorials
Bibliography	Huheey, J. E.; Keiter, E. A.; Keiter, R. L. *Inorganic Chemistry*; De Boeck Université: Brussels, 2000. Kettle, S. F. A. *Inorganic Physical Chemistry*; De Boeck Université: Brussels, 1999. Cotton, F. A.; Wilkinson, G.; Murillo, C. A. *Advanced Inorganic Chemistry*; Wiley: New York, 1999. Greenwood, N. N.; Earnshaw, A. *Chemistry of the Elements*, 2nd ed.; Pergamon Press: Oxford, 1997. Kahn, O. *Electronic Structure of Transition Elements*; Presses Universitaires de France (PUF): Paris, 1977.

Organometallic chemistry

Related course unit: Molecular synthesis and modelling		
Number of hours: 8	Number of ECTS credits: 0.75	
Year/semester: M1/S1		Language of instruction: mixed French/English
Lecturer:	Rémi Dessapt	
Objectives	• Identify the different types of ligands in the coordination sphere of an organometallic complex and the nature of their interaction with the metal centre. • Determine the characteristic quantities of an organometallic complex (number of valence electrons in the complex, number of bonds, number of valences of the metal). • Use these quantities to anticipate the potential chemical reactions of an organometallic complex or to identify the nature of a chemical reaction in which it is involved. • Analyse in detail the different stages of an industrial catalytic cycle involving an organometallic catalyst.	
Contents covered:	*1. Tools for describing organometallic complexes* - Characteristic quantities of organometallic complexes: NEV, NL and NV - Different types of ligands in organometallic chemistry - The 18-electron rule - Metal-carbonyl complexes - P-complexes of mono- and polyene - Bimetallic complexes and multiple M-M bonds *2. Reactivity in organometallic chemistry* - Dissociation reaction of a complex - Ligand substitution reaction - Oxidative addition reaction - Reductive elimination reaction - Insertion-migration and deinsertion reactions - Oxidative coupling and reductive decoupling *3. Application of organometallic complexes in catalysis* - Hydrogenation of olefins - Polymerisation of olefins - Carbonylation of methanol (Monsanto process) - Hydroformylation of olefins	
Teaching methods:	Lectures and tutorials	
Bibliography:	Online documentation on MADOC	

Modelling

Related course unit: Molecular synthesis and modelling	
Number of hours: 16	Number of ECTS credits: 0.75
Year/semester: M1/S1	Language of instruction: mixed French/English
Lecturer:	Denis Jacquemin
Objectives	• Explain the fundamental differences between classical methods and Hartree-Fock or DFT quantum methods • Distinguish the main contributions necessary for describing chemical bonds • Understand the relevance of scientific articles based on molecular modelling studies • Choose a molecular modelling method to study the simple properties of a chemical compound
Topics covered:	*1. Physical fundamentals* • Major families of theoretical methods (classical/quantum) • Founding principles and fields of application of these different families *2. Classical mechanics* • Concept of force fields • Classes and parameterisations of force fields *3. Quantum mechanics* • Advanced CLOA method: from principle to final energies • Major families of localised atomic function bases • Concept of exchange, chemical bonding, self-consistent approach and Hartree-Fock method • Introduction to DFT methods, functionals (B3LYP, PBE0, etc.) *4. Applications to concrete case studies* • Structure optimisation and conformational analysis • Theoretical descriptors of chemical reactivity • Qualitative theoretical approaches for UV/Vis, IR and NMR spectroscopy.
Teaching methods:	Classes: theoretical foundation Tutorials: introduction to the subject, enabling students to then understand the "level 2" modelling lessons specific to the different courses
Bibliography:	Online documentation on MADOC

UE: PHYSICAL AND CHEMICAL CHARACTERISATION (3 ECTS)

NMR spectrometry

Related course unit: Physico-chemical characterisation	
Number of hours: 12	Number of ECTS: 0.6
Year/semester: M1/S1	Language of instruction: French
Lecturer:	Serge Akoka
Objectives:	• Extract information (chemical shifts and couplings) from high-resolution 1D NMR spectra of the most common nuclei (1H, 13C, 15N, etc.) - Intermediate level • Determine the structure of an organic compound from NMR spectra - Intermediate level
Topics covered:	- In-depth study of the principles of NMR. - Systematic approach to elucidating molecular structures using NMR.

	- Influence of dynamic phenomena on the spectrum. - Nuclei other than 1H (couplings with heteronuclei, 13C and 15N NMR). - 1D interpretation aids (spectrum editing, isolation of a sub-spectrum). - Introduction to 2D NMR
Teaching methods:	Lectures and practical exercises for classroom-based learning Online lectures, videos and self-assessment exercises for distance learning
Bibliography	An Introduction to NMR. Serge Akoka. Online course: http://www.sciences.univ-nantes.fr/CEISAM/index.php?page=43&lang=FR Günther, H. *La Spectroscopie de RMN*; Masson: Paris, 1996.

Molecular Spectroscopy Level 1

Related course unit: Physicochemical characterisation		
Number of hours: 12	Number of ECTS credits: 0.6	
Year/semester: M1/S1		Language of instruction: mixed French/English
Lecturer:	Elena Ishow	
Objectives	• Describe an electronic transition from a quantum perspective (transition probability, Franck-Condon principle, fine structure) • Draw the Perrin-Jablonski diagram and identify the relaxation processes of an excited electronic state • Distinguish between fluorescence and phosphorescence processes (spin multiplicity, observation conditions) • Record an emission spectrum (measurement principle and experimental conditions) • Determine the quantum yield of an unknown sample from a reference • (choice of reference, choice of excitation and emission spectral ranges, choice of solvent)	
Topics covered:	- Review of the energy levels of a molecule (Born-Oppenheimer model, molecular wave function, molecular orbitals and electronic energy) - Quantum description of an electronic transition (electric dipole interactions, singlet and triplet states, spontaneous absorption and emission processes, Franck-Condon principle) - Unimolecular relaxation process (definition of the Perrin-Jablonski diagram, radiative and non-radiative processes, time scale of processes) - Characteristics of fluorescence and phosphorescence processes (quantum emission efficiencies, structural parameters, photophysical characteristics, experimental conditions) - Experimental approach to emission processes (recording an emission spectrum, equipment, measuring emission quantum yield, operating precautions)	
Teaching methods:	Face-to-face and distance learning	
Bibliography	Valeur, B. *Molecular Fluorescence: Principles and Applications*; Wiley: New York, 2004. Lakowicz, J. R. *Principles of Fluorescence Spectroscopy*, 3rd ed.; Springer: New York, 2006. Turro, N. J.; Ramamurthy, V.; Scaiano, J. C. *Principles of Molecular Photochemistry: An Introduction*; University Science Books: Sausalito, CA, 2009. Atkins, P.; de Paula, J. *Physical Chemistry*, 11th ed.; Oxford University Press: Oxford, 2022.	

Electrochemistry Level 1

Related course unit: Physicochemical Characterisation		
Number of hours: 12	Number of ECTS credits: 0.6	
Year/semester: M1/S1	Language of instruction: mixed French/English	
Lecturer:	Mohamed Boujtita	
Objectives	• Master the different aspects of an electrochemical reaction • Predict the influence of the electrolytic solution and electrode material on the electrochemical behaviour of an electroactive species	
Topics covered:	1. Electrochemical processes, concepts of potential and current 2. Electron transfer reactions at the electrode/electrolyte solution interface 3. Butler-Volmer law, Tafel's empirical law, determination of kinetic parameters (α and k°) of an electrochemical reaction 4. Mass transport: diffusion, convection and migration 5. Potential-controlled amperometric techniques, cyclic voltammetry in (stationary) and diffusion mode, chronoamperometry and chronocoulometry.	
Teaching methods:	Lectures and practical work	
Bibliography:	Online documentation on MADOC	

Mass spectrometry

Related course unit: Physicochemical characterisation		
Number of hours: 12	Number of ECTS credits: 0.6	
Year/semester: M1/S1	Language of instruction: French	
Lecturer:	Françoise Zammattio/ Pierrick Nun	
Objectives	• Identify the different mechanisms of molecule fragmentation during structural analysis by electron impact mass spectrometry. • Predict fragmentation reactions and the masses of the fragments formed for a given molecular structure. • Use the results provided by mass spectrometry to extract the molecular mass, molecular formula and structural information, and propose a developed formula.	
Topics covered:	Identification of molecular peaks. Interpretation of isotope patterns. Determining the empirical formula. Calculating the number of unsaturations. Fragmentation rules. Identification of primary and secondary characteristic fragments. Rearrangement mechanisms (Mac Lafferty and 4 centres). Interpretation of mass spectra obtained in IE.	
Teaching methods:	Tutorials	
Bibliography	Course materials for the solution characterisation techniques modules of the chemistry degree (SDM, RMN). Silverstein, R. M.; Basler, G. C.; Morill, T. C. *Spectrometric identification of organic compounds*; De Boeck Université.	

Chromatographic methods

Related EU: Physicochemical characterisation		
Number of hours: 12	Number of ECTS credits: 0.6	
Year/semester: M1/S1		Language of instruction: French
Lecturer:	Michèle Morançais	
Objectives	• Identify the types of chromatography equipment and their specific features. • Select the type of chromatography and the associated equipment according to the requirements of an analysis. • Interpret separation results in terms of molecular interactions.	
Contents covered:	Influence of physical and chemical parameters on separation Methods for selecting the separation technique and detection mode according to the nature of the analytes Separation of analytes: - in HPLC: modes, stationary and mobile phases, specific interactions, role in separation and optimisation of elution gradients in LC - in GC: interactions and separation of analytes, stationary phases, optimisation of temperature gradients, gases, injectors and injection techniques, detectors Case studies on analyte separation: physico-chemical interactions involved in analyte separation in chromatography, gradient optimisation. Signal and data processing: acquisition and integration parameters, qualitative and quantitative analysis strategies qualitative and quantitative analysis. Practical examples in quantitative analysis.	
Teaching methods:	Distance learning to standardise the prerequisite knowledge in a partial self-assessment of skills. Face-to-face training for the remainder of the course.	
Bibliography:	Online documentation on MADOC	

Block 2: Lumomat S1

UE: FROM MOLECULE TO SOLID (3 ECTS)

Coordination chemistry and electronic transitions

Related course unit: From Molecules to Solids		
Number of hours:	Number of ECTS: 1.11	
Year/semester: M1/S1	Language of instruction: French	
Lecturer:	Rémi Dessapt	
Objectives	• Characterise an inorganic molecule or solid by its absorption spectrum • Identify the nature of the electronic transition • Learn the associated terminology	
Topics covered:	Characterisation of an inorganic complex or inorganic solid via electronic transitions: 1. Crystal field theory with electronic correlation. 2. Electronic transitions and selection rules. 3. Application: characterisation via UV-visible absorption spectra of different transition metal complexes	
Teaching methods:	Face-to-face training	
Bibliography	Huheey, J. E.; Keiter, E. A.; Keiter, R. L. *Inorganic Chemistry*; De Boeck Université: Brussels, 2000. Kettle, S. F. A. *Inorganic Physical Chemistry*; De Boeck Université: Brussels, 1999. Cotton, F. A.; Wilkinson, G.; Murillo, C. A. *Advanced Inorganic Chemistry*, 6th ed.; Wiley: New York, 1999. Greenwood, N. N.; Earnshaw, A. *Chemistry of the Elements*, 2nd ed.; Pergamon Press: Oxford, 1997. Kahn, O. *Electronic Structure of Transition Elements*; Presses Universitaires de France: Paris, 1977.	

Inorganic condensation in aqueous solution

Related course unit: From molecules to solids		
Number of hours: 8	Number of ECTS credits: 1.11	
Year/semester: M1/S1	Language of instruction: mixed French/English	
Lecturer:	Rémi Dessapt	
Objectives	• Establish the hydrolysis and neutralisation reactions of metal ion complexes in aqueous solution. • Apply the partial charge model to a metal ion complex in aqueous solution to determine its average electronegativity, as well as the charges carried by the different atoms (or groups of atoms) in the molecule. • Predict the stability of a complex with respect to condensation and precipitation reactions in aqueous solution based on the partial charges of the atoms. • Establish a structural relationship between the condensed species and the monomeric precursor in aqueous solution. • Identify the nature of the reactions involved in the condensation of metal cations.	
Contents covered:	1. Introduction 2. Metal cations in aqueous solutions 2.1. Review of the physical and chemical properties of the solvent H2O	

	2.2. Metal cations in aqueous solution 2.3. Acid-base properties of cations in aqueous solutions 3. The partial charge model 3.1. Sanderson's principle of electronegativity equalisation 3.2. Examples: the water molecule and hexaaqua complexes 3.3. Approximations and limitations of the model 4. Condensation and precipitation of metal cations in aqueous solution 4.1. Concepts of condensation and precipitation in aqueous solution 4.2. Mechanisms of inorganic condensation reactions 4.3. Condensation of divalent cations 4.4. Condensation of trivalent cations 4.5. Condensation of metals with a high degree of oxidation: the case of the V5+ ion
Teaching methods:	Face-to-face training
Bibliography	Online documentation on MADOC

Practical work in inorganic chemistry

Related course unit: From molecules to solids		
Number of hours: 8	Number of ECTS credits: 0.78	
Year/semester: M1/S1	Language of instruction: mixed French	
Lecturer:	Rémi Dessapt/ Florin Popa	
Objectives	• Perform syntheses under ambient conditions or in a controlled atmosphere. • Characterise an inorganic molecule by its absorption spectrum • Apply molecular orbital theory to determine the number of metal-metal bonds in a dinuclear organometallic complex.	
Topics covered:	Synthesis and optical characterisation of molecules (coordination complexes, organometallic complexes) and inorganic solids obtained from molecular precursors in solution: 1. TP1: Synthesis and spectral study of vanadium complexes. 2. TP2: Synthesis of a dinuclear chromium (II) complex with multiple metal-metal bonds	
Teaching methods:	Face-to-face training	
Bibliography:	Online documentation on MADOC	

UE: MOLECULAR SPECTROSCOPY, CRYSTALLOGRAPHY AND ELECTROCHEMISTRY (6 ECTS)

Optical molecular spectroscopies

Related EU: molecular spectroscopy, crystallography and electrochemistry		
Number of hours: 24	Number of ECTS credits: 1.5	
Year/semester: M1/S1	Language of instruction: mixed French/English	
Lecturer:	Ivan Lucas	
Objectives	• Conceptualise and explain, from a microscopic perspective, the phenomena of light absorption, emission and diffusion by molecules • Establish whether the following are permitted or prohibited: - an electronic transition based on considerations of symmetry and electronic spin - a transition in the infrared range based on considerations of symmetry - a Raman transition • Describe Fermi resonance and hot bands in an anharmonic approach	

	• Anticipate photophysical characteristics based on molecular structures • Calculate the acid-base constant and the oxidation-reduction potential of an excited state • Define the lifetime of a sample brought to an excited state • Distinguish between a dynamic extinction process and a static extinction process • Use group theory to describe the vibration modes of a molecule or a • functional group to interpret IR absorption and Raman scattering spectra • Propose molecular structures based on complementary IR and Raman spectra • Choose the right type of spectrometer for your analysis in practice
Topics covered:	Transition selection rules (quantum description of the dipole transition moment; selection rules, Einstein coefficients) 1. Vibrational part: Rules for selecting vibrational transitions, link with Einstein coefficients Transitions induced by inelastic light scattering Relationship between molecular structures and vibrational spectra, group theory Outside the harmonic approximation: - hot band and Fermi resonance related to solvent effects - near-infrared region, towards an analytical method Raman scattering in practice, a simple analytical method (FT-Raman) Proposal for conformation and/or molecular structure based on experimental vibration spectra 2. Photophysics section: Relationship between structure and photophysical properties Properties of excited states (acidity-basicity, oxidation-reduction, polarity) Dynamic description of an excited state Description of bimolecular fluorescence quenching processes
Teaching methods:	Face-to-face and distance learning
Bibliography:	Humbert, B.; et al. Absorption Spectrometry in the IR. *Engineering Techniques*, 2012. Hollas, J. M. *Spectroscopy*, 2003. Barbillat, J.; et al. Raman Spectrometry. *Engineering Techniques*, 2002.

Crystallography and X-ray diffraction

Related teaching unit: Molecular Spectroscopy, Crystallography and Electrochemistry		
Number of hours: 20	Number of ECTS credits: 1.5	
Year/semester: M1/S1		Language of instruction: mixed French/English
Lecturer:	Olivier Hernandez	
Objectives	• Perform symmetry operations using matrix notation • Describe the structure of a solid using space group formalism • Use reciprocal space to interpret the phenomenon of diffraction by a crystal • Determine the contribution of the network and pattern on the diffraction pattern • Understand the steps involved in structural resolution from a single crystal diffraction pattern	

Topics covered:	Crystallography Direct/reciprocal lattices Seitz notation of symmetry operations Use of space groups X-ray diffraction Use of Ewald construction Applications of Bragg's law Structure factor and shape factor of a crystal Conditions for systematic extinction Experimental methods Application of *ab initio* structural resolution on single crystals Teaching methods
Teaching methods:	Lectures, tutorials and distance learning assignments using crystallography and diffraction software, which is also made available to students. Assessment: remote work not included in the course hours.
Bibliography:	Online documentation on MADOC

Electrochemistry practicals: experimental approach

Related course unit: molecular spectroscopy, crystallography and electrochemistry		
Number of hours: 8	Number of ECTS credits: 0.9	
Year/semester: M1/S1		Language of instruction: mixed French/English
Lecturer:	Mohammed Boujtita	
Objectives	• Apply electrochemical and photoelectrochemical concepts and analytical methods • Characterise conductive and semiconductive materials	
Contents covered:	The course is based on a series of case studies taken from publications. It covers electrochemical and photoelectrochemical phenomena (batteries, sensors, photovoltaic devices, etc.) and is divided into two main parts: 1. General principles of electrochemical impedance spectroscopy 2. Introduction to the analysis of impedance spectra of electrochemical systems	
Teaching methods:	A combination of face-to-face and distance learning, to give students time to complete the required work independently. Independent distance learning is not included in the number of hours indicated.	
Bibliography:	Online documentation on MADOC	

Practical work in crystallography and X-ray diffraction

Related course unit: molecular spectroscopy, crystallography and electrochemistry		
Number of hours: 8	Number of ECTS credits: 0.9	
Year/semester: M1/S1		Language of instruction: mixed French/English
Lecturer:	Olivier Hernandez	
Objectives	• Determine the crystal class of several crystals • Index the faces of a crystal using stereographic projection • Use a diffraction pattern of a single crystal and a powder to deduce the space group and lattice parameters	

Topics covered:	This experimental course allows students to master concepts covered in the Crystal structure and X-ray diffraction course unit: - Crystals on a macroscopic scale: crystal classes and stereographic projection - Exploitation of a single crystal diffraction pattern: determination of the space group (extinction conditions), choice between several structural models (calculation of intensities) - Recording and indexing a powder diagram
Teaching methods:	Practical work
Bibliography	Online documentation on MADOC

Application of group theory

Related course unit: molecular spectroscopy, crystallography and electrochemistry		
Number of hours: 12	Number of ECTS credits: 1.2	
Year/semester: M1/S1		Language of instruction: mixed French/English
Lecturer:	Florin Popa	
Objectives	• Understand the concepts of symmetry (elements and operations) • Identify the point group of a chemical compound • Manipulate the stereographic projection of a point group • Find representations with different physical objects; manipulate representative matrices • Be able to reduce a representation to irreducible representations of the point group • Find Linear Combinations Suitable for Symmetry (LCSS) • Manipulate the projection operator and the Gram-Schmidt orthogonalisation procedure • Define and identify the vibration modes of a molecule • Construct and interpret a molecular orbital diagram	
Topics covered:	Symmetry operations and elements Point groups (definition, classification, identification) Stereographic projection of a point group Non-degenerate representations, matrix representations, degenerate representations, reduction to IR Direct sum, direct product, projection operator, Linear combinations adapted to Symmetry (CLAS), orthogonalisation of vector bases Applications of group theory to molecular vibrations (IR, RAMAN) and chemical bonds (Molecular Orbitals)	
Teaching methods:	Lectures and tutorials	
Bibliography:	Online documentation on MADOC	

Block 3: Lumomat

UE: PHYSICAL AND CHEMICAL LEVEL 3 (5 ECTS)

Integrative project

Related course unit: Physical and chemical properties level 3	
Number of hours: 10	Number of ECTS: 2
Year/semester: M1/S1	Language of instruction: English
Lecturer:	Clémence Queffélec
Objectives	• Understand the complementarity between different disciplines • Adopt a multidisciplinary approach • Decontextualise knowledge acquired during the M1 • Adopt a critical approach • Experiment with and evaluate group work
Contents covered:	The aim of the integrative project is to raise students' awareness of technological innovation. It is a multidisciplinary project that brings together 3 to 5 students to carry out work ranging from molecule design to device design. All activities carried out within the project aim to bring together at least three teachers from different disciplines.
Teaching methods:	Project-based teaching: students work independently with support from teachers and PhD students. Independence will be reinforced by specific courses or seminars depending on needs.
Bibliography:	Online documentation on MADOC

Electronic imaging

Related teaching unit: Physical and chemical sciences, level 3	
Number of hours: 20	Number of ECTS credits: 1
Year/semester: M1/S1	Language of instruction: mixed French/English
Lecturer:	Anne-Claire Gaillot
Objectives	• Master basic analysis techniques, from the submicrometric scale to the atomic scale. • Select observation techniques appropriate to the material to be analysed and the information sought • sought • Select the preparation method appropriate for the nature of the sample • Interpret the data acquired (images and spectra)
Contents covered:	1. Sample preparation for electron microscopy: metallisation, polishing methods (mechanical, PIPS), ultramicrotomy, FIB cutting, cryo-preparation for bio-objects 2. Scanning electron microscopy (SEM): electron-matter interaction, various imaging modes. Dual-beam microscope, elemental analysis by EDX or WDX spectroscopy, environmental microscopy, Raman coupling 3. Transmission electron microscopy (TEM): physical origin of contrasts in an image, bright field or dark field imaging, elemental analysis and chemical mapping (EDX, STEM-EDX, EELS), chemical contrast imaging (EFTEM, HAADF), high-resolutio imaging, CCD cameras, aberration correctors, electron tomography and cryo-microscopy This module emphasises the essential concept of contrast in an image, its physical origin and how it can be manipulated to avoid experimental artefacts that lead to misinterpretation.

	Classic imaging techniques in scanning electron microscopy as well as more complex high-resolution electron microscopy techniques and recent technical advances are covered.
Teaching methods:	Face-to-face lectures, discussion of scientific publications
Bibliography:	Online documentation on MADOC

Modelling level 2

Related course unit: Physical and chemical level 3	
Number of hours: 20	Number of ECTS credits: 1.25
Year/semester: M1/S1	Language of instruction: mixed French/English
Lecturer:	Denis Jacquemin
Objectives	• Model conjugated compounds of interest for photovoltaics and organic electronics. • Choose an appropriate approach to simulate the absorption spectra of organic molecules. • Describe the nature of electronic transitions in molecules using appropriate descriptors and quantify the importance of charge transfer for these transitions. • Determine the phosphorescence spectra of molecular compounds.
Topics covered:	Electronic spectrum calculations - Practical introduction to methods for simulating excited electronic states - Modelling absorption and phosphorescence Practical work Phase 1: absorption - Determination of compound geometry - Calculation of thermodynamic parameters - Determination of vertical transition energies and spectrum simulation - Estimation of auxochromic and solvatochromic effects - Comparison with experimental data Practical work Phase 2: properties and phosphorescence - Representation of excited states and interpretation of their nature - Evaluation of the amplitude of charge transfers - Optimisation of the lowest triplet structure - Determination of vertical and adiabatic phosphorescence energies - Critique of the theoretical approaches used
Teaching methods:	Lectures (4 hours) and practical work (16 hours).
Bibliography:	Online documentation on MADOC

Experimental design

Related course unit: Physical and chemical properties, level 3	
Number of hours: 6	Number of ECTS credits: 0.75
Year/semester: M1/S1	Language of instruction: mixed French/English
Lecturer:	Hamada Boujtita
Objectives	To train students to develop an experimental design with a focus on the following two aspects: • How to choose experimental parameters for developing an experimental design • How to analyse the results of an experimental design in terms of effects and interactions.

Topics covered:	- Presentation of the experimental design approach - Choosing experimental parameters in the field of study - Determining the area of interest - Interpretation of results - Application to the optimisation of a chemical formulation
Teaching methods:	Lectures (3 hours) and tutorials (3 hours).
Bibliography:	Online documentation on MADOC

UE: MOLECULAR CHEMISTRY LEVEL 3 (6 ECTS)

Organic Chemistry

Related course unit: Molecular Chemistry Level 3		
Number of hours: 44	Number of ECTS: 3	
Year/semester: M1/S1		Language of instruction: mixed French/English
Lecturer:	Clémence Queffélec	
Objectives	• Acquire the autonomy necessary to synthesise molecules of a certain complexity using the tools provided in this module.	
Contents	This course aims to provide students with theoretical, methodological and technical knowledge in organic chemistry and a general understanding of the major reactions in modern organic synthesis. The fundamentals of retrosynthetic analysis are introduced: 1. Principles of reactivity and frontier orbitals: review of reactivity, thermodynamic and kinetic controls and kinetics, Hammond's postulate, orbital control, HSAB theory. 2. Reactivity of the carbonyl group: principles of reactivity; chemoselective reagents for reduction and oxidation, serial aromatic formylation reactions. 3. Reactivity of the carbonyl group, nucleophilic additions and chemoselectivity (organometallic), addition of neutral nucleophiles, reactivity associated with hydrogen lability hydrogen in a; reactivity of enones. 4. Principle of double and triple bond formation: Wittig, Horner-Wadsworth-Emmons, Corey-Fuchs, Bestmann-Ohira, Siegrist, Mac Murry and Knoevenagel reactions. 5. Other principles of coupling two units: Mitsunobu reaction, activated coupling reactions. Cycloaddition reactions. 6. Basics of heterocyclic chemistry (nitrogen, oxygen and sulphur heterocycles). 7. Concepts of retrosynthesis.	
Teaching methods:	PowerPoint lectures, exercise lists and practical application.	
Bibliography:	Scifinder, ACS database, Clayden, Vollhardt	

Isolobal analogy

Related course unit: Molecular Chemistry Level 3	
Number of hours: 8	Number of ECTS credits: 1.2
Year/semester: M1/S1	Language of instruction: mixed French/English
Lecturer:	Remi Dessapt
Objectives	• Predict the splitting of a transition metal block based on its electronic character and the number and position of ligands in its coordination sphere. • Use Walsh diagrams to predict the preferred geometry of a transition metal complex. • Use the concept of isolobal analogy to combine simple molecular fragments and understand the construction and stability of organic molecules and organometallic complexes.
Contents covered:	Students will use molecular orbital theory as a tool to characterise the symmetry and stability of organometallic complexes of transition metals. <u>Chapter 1: Concepts of symmetry and stability of transition metal complexes using the molecular orbital method</u> 1. Review of bonding models 2. MO diagrams of MLn complexes 3. Fields derived from Oh and BPT symmetries 4. Use of Walsh diagrams <u>Chapter 2. Concept of isolobal analogy: carboranes and metalloboranes</u> 1. Definitions and concepts 2. Isolobial organic and organometallic fragments of CH3 3. Isolobial organic and organometallic fragments of CH2 4. Isolobial organic and organometallic fragments of CH 5. Carboranes 6. Metalloboranes and clusters
Teaching methods:	Traditional lectures and tutorials
Bibliography	Online documentation on MADOC

Organometallic chemistry

Related course unit: Molecular Chemistry Level 3	
Number of hours: 18	Number of ECTS credits: 1.8
Year/semester: M1/S1	Language of instruction: mixed French/English
Lecturer:	Errol Blart
Objectives	• Integrate and use organometallic chemistry tools in the construction of complex molecular architectures. • Develop synthesis strategy and mechanistic thinking skills. • Acquire the autonomy necessary to synthesise molecules of a certain complexity using the tools provided in this module. • Propose the mechanism of an unknown catalytic transformation that is similar to a transformation covered in the course. • Deepen and interpret a catalytic cycle with a detailed understanding of the strategies to be adopted to circumvent a limiting step. • Know the cross-coupling reactions catalysed by Pd, Ni and Cu for the formation of C-C, C-N, C-O, C-S and C-P bonds.

	• Understand "modern" reactions such as C-H activation and the metathesis of olefins and alkynes. • Understand metal-catalysed oxidation and reduction reactions. • Identify the interactions that cause stereoselectivity. • Understand and possibly predict the diastereoselectivity of a reaction involving a chiral ligand.
Contents covered:	This course opens up organic chemistry (C, H, O, N, etc.) to other atoms in the periodic table such as B, Si, P, Sn, etc., by demonstrating their specific reactivity and their uses in synthesis during cross-coupling reactions catalysed by transition metals. • It addresses the use of transition metals (Pd, Ru, Co, Ti, etc.) by showing that their mechanisms of action give access to reactivity that is completely inaccessible by other means and which are at the forefront of modern chemistry. • This course describes numerous catalytic cycles, which are discussed and interpreted. • Fundamental homogeneous catalytic processes such as hydrogenation, hydrosilylation, hydroformylation, oxidation, reduction, metathesis, etc. will be covered.
Teaching methods:	Lectures, case studies and practical exercises
Bibliography:	Online documentation on MADOC

EU: LUMOMAT MATERIALS LEVEL 3 (3 ECTS)

Stimulatable materials

Related course unit: Lumomat, materials level 3		
Number of hours: 20	Number of ECTS: 1.2	
Year/semester: M1/S1		Language of instruction: mixed French/English
Lecturer:	Elena Ishow	
Objectives	• Describe the characteristics of a photochemical reaction and the different sources of light commonly used • Establish structure-property relationships for photochromic molecules and materials • Define the reaction conditions and important parameters for carrying out a photochemical reaction • Use different stimuli to modulate the functional response of electrochromic and photochromic molecules	
Topics covered:	The introduction of activatable units to modulate the optical properties (absorption, emission, refraction) of molecular systems has led to the emergence of a new family of materials, X-chromes. These materials are generating considerable interest in industry and research laboratories due to their multiple applications in physics (information storage, mechanical fracture detection, cold chain breakage), chemistry (coloured ophthalmic lenses, sunscreen) and biology (diagnostic probes, release of active ingredients). The aim here is to present the identity of these systems, the structure-property relationships and the transfer of the molecule to the material in order to design a material with controlled properties. The course will be divided into several sections: - Information storage/encoding by optical engraving - Photochemistry and photochromes	

	- Electrochromes - Switch applications
Teaching methods:	Lectures, tutorials and practical work in class
Bibliography:	Tian, H.; Zhang, J. *Photochromic Materials: Preparation, Properties and Applications*; Wiley-VCH: Weinheim, Germany, 2016. Dürr, H.; Bouas-Laurent, H. *Photochromism: Molecules and Systems*; Elsevier: Amsterdam, 2003. Feringa, B. L. *Molecular Switches*; Wiley-VCH: Weinheim, Germany, 2001.

Polymers

UE: Lumomat, Materials Level 3		
Number of hours: 24	Number of ECTS credits: 1.8	
Year/semester: M1/S1		Language of instruction: mixed French/English
Lecturer:	Christophe Chassenieux/ Sagrario Pascual	
Objectives	• Describe organic polymer materials in terms of classification, specific characteristics and properties. • Illustrate the main routes to polymers and the means of controlling chain structure and dimensions. • Describe the characterisation techniques specific to polymers. • Present and illustrate the main structure/property relationships (thermal and mechanical) of polymer materials.	
Contents covered:	<u>Introduction and general information</u>: 1. Definitions - Concepts of macromolecular chains and polymers 2. Synthetic polymers and artificial polymers: polymerisation and chemical modification 3. Chain growth processes: chain polymerisation and polycondensation 4. Structures and dimensions: chain lengths, tacticity, average molecular weights, degree of polymerisation, dispersity. 5. Measurement of molar masses and dispersity <u>Some methods of polymer synthesis</u>: 1. Living anionic polymerisation – Application to the synthesis of block copolymers 2. Polycondensation 3. Conventional radical polymerisation 4. Introduction to radical polymerisation by reversible deactivation and macromolecular engineering macromolecular 5. Chemical modification. <u>Properties of polymer solutions</u>: 1. Conformation of macromolecules, influence of short- and long-range interactions 2. Thermodynamics of polymer solutions: concept of thermodynamic quality of solvents, concentration regime. 3. Methods for characterising polymers in solution: colligative methods, viscometry and SEC. <u>Physical and mechanical properties of polymers</u>: 1. Thermal transitions of polymers (glass transition, melting, crystallisation) 2. Elements of rubber elasticity 3. Mechanical properties 4. Elements of polymer processing	

Teaching methods:	Face-to-face
Bibliography	Fontanille, M.; Gnanou, Y. *Chemistry and Physical Chemistry of Polymers*, 2nd ed.; Dunod: Paris, 2010.

EU: THERMAL ANALYSIS (1 ECTS)

Thermal analysis

Related course unit: Thermal Analysis		
Number of hours: 20	Number of ECTS credits: 1	
Year/semester: M1/S1		Language of instruction: mixed French/English
Lecturer:	Florin Popa	
Objectives:	Elementary analysis section: • Describe the role of each basic component of the various elemental analysis devices. • Prepare samples for analysis and optimise instrument settings. • Identify possible disturbances in an analysis and remedy them, • Perform a calibration by conventional calibration or by the method of measured additions, • Know the analytical performance of each method, • Determine the molecular formula of a compound based on an elemental analysis. Thermal analysis section: • Understand the principles of thermal analysis techniques and how thermal analysis equipment works, • Identify the nature of a transformation, • Determine the chemical equation of a decomposition, • Master the influence of experimental parameters. • Use raw measurement data • Calculate the activation energy of a transformation.	
Topics covered:	1: Elemental analysis Elementary analysis using atomic absorption and emission spectrometry methods, as well as ICP-AES and ICP-MS techniques for trace analysis. Theoretical principles of analysis, possibilities and limitations of each technique, and interference factors. Analysis of different elements through practical work on different matrices. *2*: Thermal analysis Thermal analysis techniques for determining the composition of a product, its purity and thermal stability. ATG, DTG, ATD and DSC equipment and techniques: analysis of possible transformations (decompositions, changes of state, glass transitions, structural changes). Influence of experimental parameters on thermal analysis measurements. Kissinger method and kinetics of phenomena.	
Teaching methods:	face-to-face, lectures, tutorials and practical work	
Bibliography:	Online documentation on MADOC	

METHODOLOGY FOR MATERIAL SYNTHESIS (1 ECTS)

Methodology for materials synthesis

Related course unit: Methodology for materials synthesis		
Number of hours: 20	Number of ECTS:	
Year/semester: M1/S1	Language of instruction: mixed French/English	
Lecturer:	Philippe Poizot	
Objectives	This course aims to introduce different common synthesis methods (chemical and electrochemical) for the development of inorganic and organic-inorganic hybrid materials. • Upon completion of this course, students will be able to: • Master the terminology related to the various synthesis processes • Propose strategies for developing materials based on a rational approach (using knowledge of thermodynamics, kinetics and electrochemistry) • Understand the relationship between the structure of a material (size, morphology, dispersity) and the synthesis route used to design it.	
Topics covered:	1. Solid-state synthesis (ceramic route): choice and shaping of reagents, atmosphere control, quenching, crystal growth phenomena, sintering, grinding and the concept of mechanosynthesis. 2. Soft chemistry: presentation of the crucial parameters controlling the precipitation of inorganic solids, synthesis processes (synthesis by decomposition of coordination complexes, the Pechini process, solvothermal synthesis, polyol synthesis, intercalation synthesis, sol-gel synthesis, self-assembly processes). Examples: synthesis of transition metal oxides, oxyhydroxides and hydroxides with control of morphology and size, crystallised organic-inorganic hybrid materials (metal organic frameworks or amorphous (organomineral polymers)), nanometric metal particles. 3. Electrodepo t : methodological aspects and structuring of deposits	
Teaching methods:	Lectures and tutorials, mainly in person	
Bibliography	Online documentation on MADOC	

ENGLISH: TOEIC PREPARATION (0 ECTS)

English: TOEIC preparation

Related course unit: TOEIC preparation		
Number of hours: 0	Number of ECTS: 0.75	
Year/semester: M1/S1	Language of instruction: English	
Lecturer:	Emmanuel Vincent	
Objectives	*Prepare to obtain an English language certification (level B2 and above):* • Recognise and anticipate English certification formats. • Complete the answers required by certification tests. • Optimise certification results through a work methodology applied during training sessions.	

Topics covered:	1. Presentation of formats 2. Training exercises 3. Tips for optimising your score
Teaching methods:	Remote
Bibliography	Byrne, M.; Dickinson, M. *200% TOEIC 2017 Listening & Reading*; 2016. Mayer, D.; Murdoch Stern, S. *TOEIC® La Méthode Réussite*; 2011. Trew, G. *Tactics for TOEIC® Listening and Reading Test*; 2007. Gear, J.; Gear, R. *Cambridge Grammar and Vocabulary for the TOEIC Test*; 2010.

Block 4: M1 LUMOMAT S2

UE: GENERAL TRAINING (3 ECTS)

English

Related course unit: General Education		
Number of hours: 22	Number of ECTS credits: 0.75	
Year/semester: M1/S1	Language of instruction: mixed French/English	
Lecturer:	Emmanuel Vincent	
Objectives	• Master the common terminology related to your field of specialisation • Present and explain scientific content related to chemistry, in accordance with scientific and institutional formats and expectations • Argue and defend a point of view in a scientific discussion. Presentations will be made with minimal use of notes, in clear and phonologically correct English.	
Contents covered:	1. Development of specialised scientific vocabulary 2. Analysis of specialised scientific texts 3. Analysis of audio or video documents 4. Oral practice in context	
Teaching methods:	Face-to-face	

Professional relevance

Related course unit: General education		
Number of hours: 8	Number of ECTS credits: 0.25	
Year/semester: M1/S1	Language of instruction: mixed French/English	
Lecturer:	*To be defined*	
Objectives	• Decode an internship offer • Write a cover letter and CV that are consistent with your application and the company's needs of the company. • Argue objectively and factually in a recruitment situation	
Contents covered:	Internship search support: 8 hours of face-to-face tutorials dedicated to helping you find an internship (identifying the different levers for finding internships, the advantages for writing CVs and cover letters, how to prepare for an interview).	
Teaching methods:	Assessment will be based on a role-play simulation of a recruitment interview. (30 minutes per student)	
Bibliography:	Theoretical and practical teaching for approximately 20-30 minutes. This is followed by participatory work for each project team, monitored by the teacher or professional speaker.	

Photosciences

Related course unit: General training		
Number of hours: 6	Number of ECTS credits: 0.5	
Year/semester: M1/S1		Language of instruction: mixed French/English
Lecturer:	Clémence Queffélec	
Objectives	• Understand the different areas of photochemistry and their fields of application	
Topics covered:	I General introduction to photochemistry applied to health, the environment and catalysis	
Teaching methods:	In person	

Autumn school

Related course unit: General training		
Number of hours: 10	Number of ECTS credits: 0.25	
Year/semester: M1/S1		Language of instruction: mixed French/English
Lecturer:	Clémence Queffélec	
Objectives:	• opening up to the world of academic and industrial research	
Topics covered:	lectures	
Teaching methods:	lectures	

Art, science and society

Related EU: General education		
Number of hours: 10	Number of ECTS credits: 0.75	
Year/semester: M1/S1		Language of instruction: mixed French/English
Lecturer:	*Description to follow*	
Objectives	*Description to follow*	
Topics covered:	*Description to follow*	
Teaching methods:	*Description to follow*	

Chemical risks

Related EU: General training		
Number of hours: 4	Number of ECTS credits: 0.5	
Year/semester: M1/S2		Language of instruction: mixed French/English
Lecturer:	Virginie Blot	
Objectives	• Identify the health and safety risks they will face in their professional life • Identify ways of preventing the risks they will face in their professional life	
Topics covered:	Raise students' awareness of health and safety risk management in chemistry laboratories or more generally in their future professional activities. Prepare students for the CNRS NEO self-training module, which is compulsory for all new entrants to a CNRS research laboratory.	
Teaching methods:	Distance learning: INRS e-training on chemical risks "Acquiring basic knowledge of chemical products". Face-to-face**:** prevention of risks that students will encounter in their future professional life	

EU: INTERNSHIP (27 ECTS)

The internship plays an important role in the Lumomat Master's programme, which is based on close interaction between research and technological innovation. Students will be integrated into a national or international research team, or into industry.

Duration: 4 to 6 months	Number of ECTS: 27	
Year/semester: M1 / S2	Language of instruction: French/English	
Lecturers:	Clémence Queffelec	
Objectives	• Implement a scientific approach in personal fundamental or applied research work by drawing on the scientific and technical knowledge acquired in the first semester of the Master's programme • Integrate into a multidisciplinary team in a professional environment • Develop autonomy in the workplace and propose initiatives • Achieve true cultural and linguistic immersion during internships abroad • Analyse and summarise the results of their work in a written report and an oral presentation	

Mobility of students enrolled in the Lumomat Master's programme during the internship:

This programme promotes international mobility among students by providing them with access to the international network of teacher-researchers at partner laboratories.

€Students receive a mobility grant of €500 to €700 per month, depending on the destination country. They may also be eligible for a €1,000 installation grant offered by the Regional Council, subject to eligibility.

Hosting foreign students for internships in our partner laboratories:

Foreign students wishing to undertake an internship in one of our partner laboratories must send their application, accompanied by their CV and a summary of their areas of interest, to the programme coordinators. If the application is deemed eligible, an interview will be offered to discuss their objectives in more detail.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