Master's Degree in Chemistry

"Light, Molecules, Matter" Course

Graduate Programme

Lumomat

Master's 1 Syllabus

Nantes Université

CONTENTS

INTRODUCTION

Our Lumière Molécules, Matière (Lumomat) programme is accredited as a Master's and Doctorate programme (CMD)_ by Nantes University. This is an integrated programme that offers excellent opportunities for those wishing to pursue a career in academic research, as well as 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 field of photosciences, particularly photochemistry, which has applications in a number of key areas 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 partners offer you the opportunity to personalise your course in accordance with the orientation of your project professional. The workshops and practical work are supported by state-of-the-art equipment available at the platforms and 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 1 PROGRAMME COORDINATORS

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TEACHING LOCATION

Faculty of Science and Technology
Lombarderie Campus
2, rue de la Houssinière
BP 92208
44322 Nantes Cedex 3

SKILLS DEVELOPED

By the end of the Master's programme, you will have:

- Developed an understanding of the business world and become aware of the concept of entrepreneurship.
- Gained experience in project management.

You will be able to:

- Use molecular and supramolecular engineering techniques to synthesise functional materials,
- Propose eco-compatible synthesis routes for these innovative materials,
- Selecting the appropriate characterisation techniques and theoretical models to optimise the properties of functional materials.
- Restore knowledge about organic materials, their outlets and applications,
- Supervise and lead R&D projects in the field of organic materials (molecular and electronic photonics), 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

As a graduate of the LUMOMAT Master's programme in Chemistry, you will be able to take up a position as an engineer (and eventually hold a management position in a company related to R&D and innovative project management). You will also be able to enter public research at the level of a research engineer by passing a competitive examination in major public research organisations (universities, CNRS, INRA, INSERM, etc.).

↳ Exemples d'emplois occupés par nos anciens·nes étudiants·es après leur Master

- Chimiste de production
- Chimiste analytique
- Ingénieur matériaux
- Police scientifique
- Ingénieur technico-commercial
- Ingénieur recherche et développement
- Ingénieur étude et développement
- Ingénieur en électronique imprimée
- Concepteur-illustrateur en médiation scientifique

If you choose to continue your studies at PhD level, in France or abroad, you will have easy access to various types of thesis funding (e.g. CIFRE-type grants in conjunction with a company, funding via calls for projects from EUR LUMOMAT and its network).

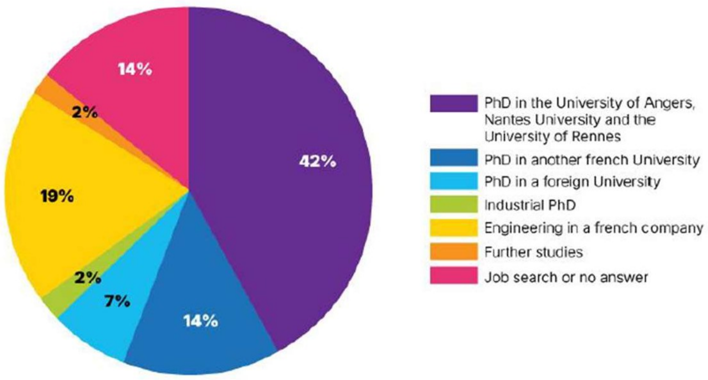
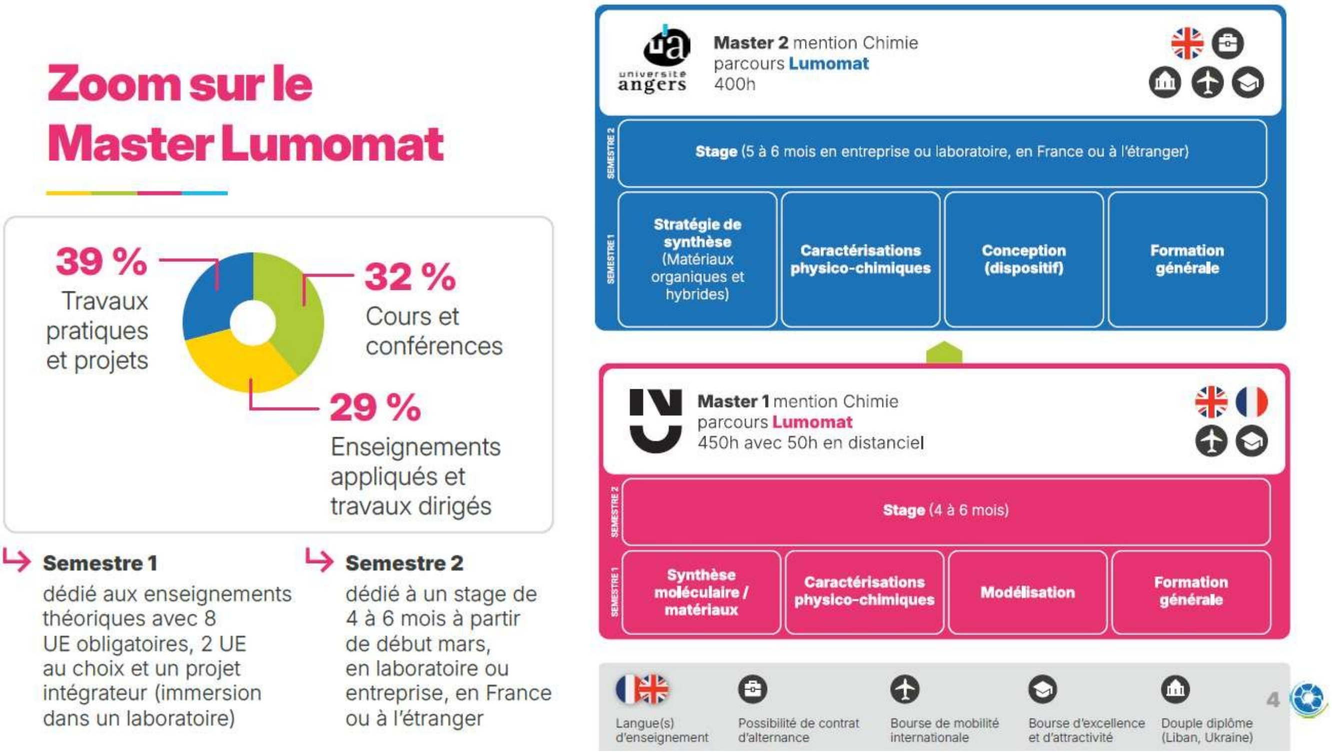


Figure 29. Diagram showing the professional integration of Master students from the 2020-2024 cohorts

PROGRAMME STRUCTURE



Mobility assistance

If you wish to undertake one or more internships abroad, the programme can provide you with substantial financial support, proportionate to the cost of living in the target country (up to €2,000), in addition to regional assistance with travel expenses (Envoléo grant: from €1,000 to €2,000 based on social criteria in 2025).

JOIN THE LUMOMAT MASTER'S PROGRAMME

Attractiveness grants

EUR Lumomat offers a scholarship of excellence (€1,500/year) to the best candidates of French or foreign nationality (selection based on application).

Foreign students may also apply for the Eiffel Excellence Scholarship (Campus France), as well as any scholarships offered by their embassy.

Students from foreign universities who are hosted as part of a credit transfer or internship programme may also be eligible for a host scholarship.

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 (UE): MOLECULAR SYNTHESIS AND MODELLING (3 ECTS)

Concepts of solvents and reactivity

Related teaching 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:	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.) - Select 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):* - 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

Affiliated EU: 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. Reminders - Coordination complexes (Ligand types / Complex geometry) 2. Reminders - Use of a crystal field bonding model 3. Stability of transition metal complexes 4. Introduction to the reactivity of transition metal complexes.
Teaching methods Teaching:	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

Affiliated teaching 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 properties of an organometallic complex (number of valence electrons in the complex, number of bonds, valence number of the metal). • Use these values 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 - The 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 desinsertion reactions - Oxidative coupling and reductive decoupling *3. Application of organometallic complexes in catalysis* - Hydrogenation of olefins - Polymerisation of olefins - Methanol carbonylation (Monsanto process) - Hydroformylation of olefins (oxo synthesis) oxo)	
Teaching methods :	Lectures and tutorials	
Bibliography:	Online documentation on MADOC	

Modelling

Related teaching 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
Contents covered:	1. *Physical fundamentals* • Major families of theoretical methods (classical/quantum) • Fundamental 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:	Lectures: 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

Teaching unit: PHYSICAL AND CHEMICAL CHARACTERISATIONS (3 ECTS)

NMR spectrometry

Related course unit: Physicochemical characterisations	
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
Contents 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 (coupling with heteronuclei, 13C and 15N NMR). - 1D interpretation assistance technique (spectrum editing, sub-spectrum isolation). - Introduction to 2D NMR
Teaching methods Teaching methods:	Lectures and practical exercises for face-to-face 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. *NMR Spectroscopy*; Masson: Paris, 1996.

Molecular spectroscopy level 1

Related teaching unit: Physicochemical characterisation		
Number of hours: 12	Number of ECTS credits: 0.6	
Year/semester: M1/S1		Language of instruction: mixed French/English
Teacher:	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 value of an unknown sample from a reference • (choice of reference, choice of excitation and emission spectral ranges, choice of solvent)	
Contents covered:	- Reminder 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, operational precautions) procedures)	
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 teaching unit: Physicochemical Characterisation		
Number of hours: 12	Number of ECTS credits: 0.6	
Year/semester: M1/S1		Language of instruction: mixed French/English
Lecturer referent:	Mohamed Boujtita	
Objectives:	• Master the various 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 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 convective (stationary) and diffusion regimes, chronoamperometry and chronocoulometry.	
Teaching methods :	Lectures and practical work	
Bibliography:	Online documentation on MADOC	

Mass spectrometry

Related EU: 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 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 formula .	
Contents covered:	Identification of molecular peaks. Interpretation of isotopic patterns. Determination of molecular formula. Calculation of unsaturation number. Fragmentation rules. Identification of primary and secondary characteristic fragments. Rearrangement mechanisms (Mac Lafferty and 4 centres). Interpretation of mass spectra obtained by IE.	
Teaching methods Teaching methods:	Tutorials	
Bibliography:	Course materials for the chemistry degree programme's solution characterisation techniques modules (SDM, NMR). Silverstein, R. M.; Basler, G. C.; Morill, T. C. *Spectrometric identification of organic compounds* ; De Boeck Université.	

Chromatographic methods

Related course unit: 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 chromatography mode and associated equipment according to the requirements of an • analysis. • Interpret the separation results in terms of molecular interactions.
Contents covered:	Influence of physicochemical parameters on separation Methods for choosing 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, involvement 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: physicochemical 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 strategies. Practical examples of quantitative analysis.
Teaching methods:	Distance learning to standardise prerequisite knowledge in a process partial self-assessment of skills. Face-to-face training for the rest of the course.
Bibliography:	Online documentation on MADOC

Block 2: Lumomat S1

EU: 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
Contents 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 teaching 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. Reminder 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 solution 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 Teaching methods:	Face-to-face training
Bibliography:	Online documentation on MADOC

Practical work in inorganic chemistry

Related teaching 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.	
Contents 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 Teaching:	Face-to-face training	
Bibliography:	Online documentation on MADOC	

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

Optical molecular spectroscopies

Related course unit: molecular spectroscopy, crystallography and electrochemistry	
Number of hours: 24	Number of ECTS: 1.5
Year/semester: M1/S1	Language of instruction: mixed French/English
Lead teacher:	Ivan Lucas
Objectives:	• Conceptualise and explain, from a microscopic perspective, the phenomena of light absorption, emission and scattering 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 using an anharmonic approach • Anticipate photophysical characteristics based on molecular structures • Calculate the acid-base constant and redox potential of an excited state • Define the lifetime of a sample brought to an excited state • Know how to distinguish between a dynamic quenching process and a static quenching process • Use group theory to describe the vibration modes of a molecule or • functional group to interpret IR absorption and Raman scattering spectra • Propose molecular structures based on complementary IR and Raman spectra • Choosing 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 section: 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 domain, 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. Photophysical section: Relationship between structure and photophysical properties Properties of excited states (acido-basicity, oxidation-reduction, polarity) Dynamic description of an excited state Description of bimolecular fluorescence quenching processes
Teaching methods Teaching methods:	Face-to-face and distance learning
Bibliography:	Humbert, B.; et al. IR Absorption Spectrometry. *Les Techniques de l'Ingénieur*, 2012. Hollas, J. M. *Spectroscopy*, 2003. Barbillat, J.; et al. Raman Spectrometry. *Les Techniques de l'Ingénieur*, 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	
Teacher :	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 lattice and pattern on the diffraction pattern • Understand the steps involved in structural resolution from a single crystal diffraction pattern	
Contents covered:	Crystallography Direct/reciprocal lattices Seitz notation of symmetry operations Use of space groups X-ray diffraction Use of Ewald's construction Applications of Bragg's law Structure factor and form 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 using crystallography and diffraction software, which is also made available to students. Assessment: remote work not included in the teaching hours for this course.	
Bibliography:	Online documentation on MADOC	

Electrochemistry practicals: experimental approach

Related teaching 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	
Teacher:	Mohammed Boujtita	
Objectives:	• Mobilise the concepts and analytical analytical electrochemical and photoelectrochemical • Characterising 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	

TP Crystallography and X - r a y diffraction

Affiliated teaching 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 teaching allows students to grasp concepts covered in the Crystallography and X-ray Diffraction course unit: - Crystals on a macroscopic scale: crystal classes and stereographic projection - Use 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 Teaching methods:	Practical work
Bibliography:	Online documentation on MADOC

Application of group theory

Related teaching 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 Symmetry-Adapted Linear Combinations (SALCs) • Manipulate the projection operator and the Gram-Schmidt orthogonalisation procedure • Define and identify the vibration modes of a molecule • Constructing and interpreting a molecular orbital diagram
Topics covered:	Operations and elements of symmetry 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, Symmetry-Adapted Linear Combinations (SALC), 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 CHEMISTRY LEVEL 3 (5 ECTS)

Integrative project

Related EU: Physico-chemical 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 the knowledge acquired during the M1 • Adopt a critical approach • Experiment with and evaluate group work	
Topics 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 of the activities carried out within the project aim to bring together at least three teachers from different disciplines.	
Teaching methods:	Project-based learning: students work independently with support from teachers and doctoral students. Independence will be supported by specific courses or seminars as needed.	
Bibliography:	Online documentation on MADOC	

Electronic imaging

Related EU: Physico-chemical 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 • Choose the preparation method appropriate to the nature of the sample • Interpreting acquired data (images and spectra)	
Topics 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-resolution 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 to manipulate it in order 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 classes, discussion of scientific publications
Bibliography:	Online documentation on MADOC

Level 2 modelling

Related teaching unit: Physicochemical 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 - Pragmatic 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 auxochrome and solvatochrome effects - Comparisons with experimental data Practical work Phase 2: properties and phosphorescence - Representation of excited states and interpretation of their nature - Evaluation of the amplitude of load transfers - Optimisation of the lowest triplet structure - Determination of vertical and adiabatic phosphorescence energies - Critique of the theoretical approaches used	
Teaching methods Teaching:	Lectures (4 hours) and practical work (16 hours).	
Bibliography:	Online documentation on MADOC	

Experimental design

Related teaching 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 plan 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 Teaching methods:	Lectures (3 hours) and tutorials (3 hours).	
Bibliography:	Online documentation on MADOC	

EU: MOLECULAR CHEMISTRY LEVEL 3 (6 ECTS)

Organic Chemistry

Related EU: 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 using the tools provided in this module.	
Contents covered:	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, Hammond's postulate, orbital control, HSAB theory. 2. Reactivity of the carbonyl group: principles of reactivity; chemoselective reduction and oxidation reagents, aromatic series formylation reactions. 3. Reactivity of the carbonyl group, nucleophilic additions and chemoselectivity (organometallic), addition of neutral nucleophiles, reactivity associated with the lability of hydrogen in a; reactivity of enones. 4. Principles of double and triple bond formation: Wittig, Horner-Wadsworth-Emmons, Corey-Fuchs, Bestmann-Ohira, Siegrist, Mac Murry and Knoevenagel reactions. 5. Other principles for linking two units: Mitsunobu reaction, activated coupling reaction. 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 teaching 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 bond breaking of a transition metal based on the electronic character, 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. Isolobal 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. Metalloborane and clusters
Teaching methods 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 utilise organometallic chemistry tools in the construction of complex molecular architectures. • Develop skills in synthesis strategy and mechanistic thinking. • Acquire the autonomy necessary to carry out the synthesis of molecules of a certain complexity using the tools provided in this module. • Propose the mechanism of an unknown catalytic transformation, but one that is related to a transformation covered in the course. • Deepen and interpret a catalytic cycle with a detailed understanding of the strategies to be adopted to overcome a limiting step. • Understand the cross-coupling reactions catalysed by Pd, Ni and Cu for the formation 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.
Topics covered:	This course introduces organic chemistry (C, H, O, N, etc.) to other atoms in the periodic table such as B, Si, P, Sn, etc., 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 provide access to reactivity that would otherwise be completely inaccessible and which are at the forefront of modern chemistry. • This course describes numerous catalytic cycles, which are discussed and interpreted. • processes catalysis homogeneous fundamental such as hydrogenation, hydrosilylation, hydroformylation, oxidation, reduction, metathesis, etc. will be covered.
Terms and conditions Teaching:	Lectures, case studies and practical exercises
Bibliography:	Online documentation on MADOC

EU: LUMOMAT MATERIALS LEVEL 3 (3 ECTS)

Stimulatable materials

<table>
<tr><td colspan="3">Related EU: Lumomat, materials level 3</td></tr>
<tr><td colspan="2">Number of hours: 20</td><td>Number of ECTS: 1.2</td></tr>
<tr><td colspan="2">Year/semester: M1/S1</td><td>Language of instruction: mixed French/English</td></tr>
<tr><td>Lecturer
:</td><td colspan="2">Elena Ishow</td></tr>
<tr><td>Objectives</td><td colspan="2">• Describe the characteristics of a photochemical reaction and the different common sources of light.
• Establishing structure-property relationships for photochromic molecules and materials
• Define the reaction conditions and parameters important for achieving a photochemical reaction
• Utilise different stimuli to modulate the functional response of electro- and photochromic molecules photochromic molecules</td></tr>
<tr><td>Contents covered:</td><td colspan="2">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 excitement in industry and research laboratories due to their multiple applications in physics (information storage, mechanical fracture detection, cold chain disruption), chemistry (tinted ophthalmic lenses, sunscreen) and biology (diagnostic probes, active ingredient release).
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
- Applications of switches</td></tr>
</table>

Teaching methods Teaching methods:	Lectures, tutorials and practical sessions in person
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

Affiliated EU: Lumomat, Level 3 Materials		
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 methods of accessing polymers and the means of controlling the structure and dimensions of chains. • Describe 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. Measurements 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 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 Teaching methods:	Face-to-face	
Bibliography:	Fontanille, M.; Gnanou, Y. *Chemistry and Physical Chemistry of Polymers*, 2nd ed.; Dunod: Paris, 2010.	

TA: THERMAL ANALYSIS (1 ECTS)

Thermal analysis

Related course unit: Thermal Analysis		
Number of hours: 20	Number of ECTS: 1	
Year/semester: M1/S1	Language of instruction: mixed French/English	
Teacher in charge:	Florin Popa	
Objectives:	Elementary analysis section: • Describe the role of each basic component of the various basic analysis devices. • Prepare samples for analysis and optimise instrument parameters. • Identify possible disruptions to an analysis and remedy them. • Perform a titration using conventional calibration or the titration method, • Understand the analytical performance of each method. • Determine the molecular formula of a compound from an elemental analysis. Thermal analysis section: • Understand the principles behind the techniques and how a thermal analysis device works. • Identify the nature of a transformation. • Determine the chemical equation for a decomposition. • Master the influence of experimental parameters, • Use raw measurement data, • Calculate the activation energy of a transformation.	
Topics covered:	1 : Elementary analyses Basic 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 associated interferences. Analysis of different elements through practical work on different matrices. 2 : Thermal analyses Thermal analysis techniques for determining a product's composition, purity and thermal stability. ATG, DTG, ATD, 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 practicals	
Bibliography:	Online documentation on MADOC	

METHODOLOGY FOR MATERIAL SYNTHESIS (1 ECTS)

Methodology for materials synthesis

Related teaching unit: Methodology for materials synthesis	
Number of hours: 20	Number of ECTS credits:
Year/semester: M1/S1	Language of instruction: mixed French/English
Lecturer:	Philippe Poizot
Objectives:	This course aims to introduce various 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 reasoned approach (using knowledge of thermodynamics, kinetics and electrochemistry) • Understanding the relationship between the structure of a material (size, morphology, dispersity) and the synthesis pathway used to design it.
Topics covered:	1. Solid-state synthesis (ceramic route): choice and shaping of reagents, atmosphere control, quenching, crystal growth phenomenon, sintering, grinding and the concept of mechanosynthesis. 2. Green 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 oxides, oxyhydroxides and hydroxides of transition metals with control of morphology and size, crystallised organic-inorganic hybrid materials (metal organic frameworks or amorphous (organomineral polymers)), nanometric metal particles. 3. Electrodeposition: methodological aspects and structuring of deposits
Teaching methods Teaching methods:	Lectures and tutorials, mainly in person
Bibliography:	Online documentation on MADOC

ENGLISH: TOEIC PREPARATION (0 ECTS)

English: TOEIC preparation

Related EU: TOEIC preparation	
Number of hours: 0	Number of ECTS credits: 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 working methodology applied during training sessions.
Contents covered:	1. Presentation of formats 2. Training exercises

	3. Tips for optimising your score
Teaching methods:	Distance learning
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: 0.75	
Year/semester: M1/S1		Language of instruction: mixed French/English
Lecturer :	Emmanuel Vincent	
Objectives:	• Master common terminology related to one's 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 the context of a scientific discussion. Presentations will be made with minimal use of notes, and in clear and phonologically correct English clear and phonologically correct English.	
Content 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 Teaching:	Face-to-face	

Professional focus

Related teaching 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 determined*	
Objectives:	• Decoding an internship offer • Write a cover letter and CV that are consistent with your application and the company's needs • of the company. • Present arguments objectively and factually in an oral recruitment situation	
Topics covered:	Support in finding internships: 8 hours of face-to-face tutorials dedicated to helping students finding internships (identifying the various tools for finding internships, tips for writing CVs and cover letters, how to prepare for an interview).	
Teaching methods :	Assessment will be based on a role-play involving a mock recruitment interview (30 minutes per student).	
Bibliography:	Theoretical and practical teaching lasting approximately 20/30 minutes. Then participatory work for each project team, supervised by the teacher or professional speaker professional.	

Photosciences

Related teaching unit: General education		
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 basic concepts of photochemistry and their fields of application	
Topics covered:	General introduction to photochemistry applied to health, the environment and catalysis	
Teaching methods:	Face-to-face	

Autumn school

Related teaching 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:	• Introduction to the world of academic and industrial research	
Topics covered:	Theme determined each year	
Teaching Teaching methods:	Lectures and workshops	

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 :	Pierre Teissier	
Objectives:	• Read and analyse scientific publications in the humanities and social sciences • To learn about academic research through practice • Formalise, in written and oral form, a reflective, critical and/or comparative analysis of the place and role of science and technology in contemporary societies, through the analysis of science fiction and animated films	
Contents covered:	Reading research publications and overviews of the humanities and social sciences, particularly in the field of film analysis, artistic images and art history. Individual and collective reflection on certain academic research methods: relationships with empirical data; comparative and contradictory practices; collective and creative dimensions; formalisation in written form (collective analysis report) and oral form (presentation to the class). Convergences and differences between research methods in the natural sciences and social sciences.	
Teaching methods :	Collective film analysis work in groups of 3-4 students, supervised by the teacher , resulting in a written report and a collective oral presentation	

Chemical risks

Related teaching unit: General education		
Number of hours: 4	Number of ECTS credits: 0.5	
Year/semester: M1/S2	Language of instruction: mixed French/English	
Teacher :	Virginie Blot	
Objectives:	• Identify the health and safety risks they will face in their professional life • Identify ways to prevent the risks they will face in their professional life	
Topics covered:	Raising student awareness of health and safety risk management in chemistry laboratories and, more generally, in their future professional activities. Preparation for validation of the CNRS NEO self-training module, which is compulsory for all new entrants 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 face 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
Teachers references:	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 one's work in the form of a written report and an oral presentation results of your work		

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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