Master Material sciences

Specialty "Innovative Materials and Energy Systems"

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Graduate Programme E-Mat

Syllabus for the first year of the master's programme

Nantes Université

CONTENTS

INTRODUCTION

E-Mat is a graduate program that takes place in Nantes University. It is an integrated program that opens higher opportunities for those who want to develop their research career path in a doctorate.

This program focuses on the emergence of innovative functional material solutions and optimization of performance, reliability and flexibility for the production, conversion, transfer and storage of energy, energy systems, and advanced devices and technologies. It draws on research excellence in physics, chemistry and engineering of (nano)materials, multi-scale modelling, advanced characterization and thermal management.

It is a part of Master of Material Sciences. **Courses in master I are taught in French** and students will have a chance to carry out their research project in an international environment in two of our high-level laboratories (Institute of Materials of Nantes Jean Rouxel, IMN & Laboratory of Thermal Engineering and Energy, LTEN) and to train with specialists on top-level instruments. In order to perfect their English for the Master 2 course, students have access to the 7speaking LMS (Learning Management System) platform, which offers a wide variety of learning situations.

CAREER OPPORTUNITIES

Graduating from our program at the Master or PhD level will open great opportunities to be hired in Research and Development department of industrial companies involved in many sectors, such as:

- Materials
- New and Renewable energies
- Energy production, conversion and storage
- Information and Communication Technologies, Microelectronics
- Transportation/Aerospace…

You could become :

- Engineer and executive in Research, Development and Innovation
- Engineer and executive in consulting firms
- Materials engineer
- Academic researcher after a PhD…

PROGRAM LEADERS ON MASTER 1 LEVEL

Philippe MOREAU	Philippe.Moreau@univ-nantes.fr
Patricia BERTONCINI	Patricia.Bertoncini@univ-nantes.fr

TEACHING LOCATIONS

UFR Sciences et Techniques
Campus Lombarderie
2, rue de la Houssinière
BP 92208
44322 Nantes Cedex 3

SKILLS BASED APPROACH

The learning objectives for the Master's programme are formulated as follows :

1. Formulate a solution to a complex problem in the field of functional materials, associated processes and energy:
   - ✓ by mobilizing theoretical and technical knowledge and the most relevant models,
   - ✓ by adopting a rigorous scientific approach and reasoning,
   - ✓ by positioning oneself in relation to the state of the art.

2. Develop experimentation/modeling in Materials & Energy :
   - ✓ using validated protocols and/or those found in the bibliography,
   - ✓ rigorously implement the experimental or modeling protocol,
   - ✓ respecting good laboratory practice,
   - ✓ by developing the experimental/modeling approach to ensure reproducibility and reliability.

3. Analyze data collected in a fundamental or applied research study :
   - ✓ by choosing the most appropriate tools and graphic representations
   - ✓ by critically comparing them with current theories and results found in the bibliographical study,
   - ✓ by exchanging information with specialists if necessary.

4. Integrate Research and Development in a professional industrial or academic environment :
   - ✓ deliver a scientific message that is structured, clear and synthetic, both in writing (article, report) and orally (team meeting, conference), in one's mother tongue and in English, adapted to the audience and context,
   - ✓ respecting the principles of ethics, deontology, environmental responsibility and scientific integrity,
   - ✓ by developing their knowledge and skills through ongoing training and constant monitoring,
   - ✓ by taking part in technological innovation and/or knowledge creation.

COURSE SCHEDULING

September to january:	February to march :	April to June/July
Lectures and practical training Semester 1	Lectures and practical training Semester 2	From 2 to 4 month Internship

NB : Students enrolled in a foreign university may do an internship in one of our laboratories at any time of the year, subject to the constraints of their home institution.

PROGRAMME STRUCTURE

The Master 1 programme is organised into groups of units:

SEMESTER 1	SEMESTER 2
Fundamentals of physics	X
Elaboration of (nano)materials 1	
Characterization of materials 1	
Propriétés des matériaux et systèmes pour l'énergie	
Preparing for professional integration 1	
X	Modeling 1
X	**Internship**

HOW TO APPLY FOR JOINING MASTER 2 E-MAT

Requirements

Prerequisites and various admission procedures are detailed on the course description on the Nantes University website:
https://sciences-techniques.univ-nantes.fr/formations/masters/graduate-programme-innovative-materials-and-energy-systems-e-mat-master-level

Scholarships

A welcome grant of **1 500€** is available to foreign students enrolling at Nantes Université.
Foreign students who come within the framework of a partnership agreement can also **benefit from a room or studio in a student residence at a preferential rate** (**beetween 270€ and 390 €**). They are also **exempt from registration fees.**
Internships of more than two months are rewarded in France with approximately **€600 per month**.
Students can also apply to excellence scholarships G. Eiffel or other scholarships proposed by their ambassy.

You can find the information you need to estimate your budget for living and studying in France on the University website :
https://english.univ-nantes.fr/education/prepare-your-stay/financing-your-studies

Fundamental of physics

TEACHING UNIT (TU): STATISTICAL PHYSICS AND SOFT MATTER (3 ECTS)

Statistical Physics

Affiliated TU : Statistical Physics and soft matter (3 ECTS)	
Duration : 16h	
Year/semester : M1/S1	Language: french
Main teacher:	Patricia Bertoncini
Learning objectives:	• Understand the relationship between statistical physics and thermodynamics • Calculate thermodynamic quantities in micro-canonical, canonical and grand canonical sets
Content covered:	1. Introduction to statistical physics 2. Isolated systems at equilibrium - Microcanonical ensemble 3. Canonical ensemble 4. Grand canonical ensemble
Teaching methods:	*Lectures and exercises*
Bibliography :	Physique statistique de B. Diu, C. Guthmann, D. Lederer et B. Roulet, édition Hermann Physique statistique des phénomènes élémentaires aux phénomènes collectifs de C. Texier et G. Roux, édition Sciences Sup Dunod Physique statistique cours, exercices et problèmes corrigés de H. T. Diep, édition ellipses
Prerequisites :	Basic knowledge in Physics and Physical Chemistry for a Bachelor student

Soft matter

Affiliated TU : Statistical Physics and soft matter (3 ECTS)	
Duration: 16h	
Year/semester : M1/S1	Language: english
Main teacher:	Patricia Bertoncini
Learning objectives:	• Understand how the characteristics of a soft matter object on the atomic and/or molecular scale determine its properties on the macroscopic scale.
Content covered:	1. Introduction to Soft Matter Physics 2. Intermolecular interactions 3. Force measurements at the single molecule/cell scale 4. Surfaces, interfaces and wettability phenomena 5. Applications
Teaching methods:	Lectures and exercices, study on articles
Bibliography :	Intermolecular and surface forces, J. Israelachvili, Academic Press Physique de la matière molle, F. Brochard-Wyart, P. Nassoy et P.-H. Puech, DUNOD Soft Matter Physics ; Editors · Mohamed Daoud, Claudine E. Williams ; DOI · https://doi.org/10.1007/978-3-662-03845-1 ; Publisher · Springer
Prerequisites :	Basic knowledge in Physics and Physical Chemistry for a Bachelor student

TU : QUANTUM AND ATOMIC PHYSICS (5 ECTS)

Quantum physics

Affiliated TU : Quantum and atomic physics (5 ECTS)		
Duration: 24h		
Year/semester : M1/S1		Language: french
Main teacher:	Thierry Gousset	
Learning objectives:	• Know the formalism of the theory of time-independent perturbations for degenerate and non-degenerate states • Determine changes in the energy spectrum for simple perturbations • Know the formalism of time-dependent perturbation theory • Be able to calculate the transition probability for simple time-dependent disturbances • Concepts of scattering amplitude, cross-section and the Born approximation • Know how to perform calculations in the Born approximation for simple potentials	
Content covered:	1. Background (quantum harmonic oscillator, quantum angular momentum, hydrogen atom) 2. Scattering by a potential (scattering amplitude, cross-section, Born approximation) 3. Stationary perturbations (first and second order for non-degenerate states; first order for degenerate states) 4. Application to the study of the fine structure of the hydrogen atom 5. Time-dependent perturbations (step or sinusoidal perturbation, Fermi's golden rule) 6. Application to the study of the interaction of an atom with an electromagnetic wave	
Teaching methods:	Lectures and tutorials.	
Prerequisites :	Undergraduate quantum mechanics. Fourier transform, analysis in the complex plane.	

Atomic physics

Affiliated TU : Quantum and atomic physics (5 ECTS)		
Duration: 24h		
Year/semester : M1/S1		Language: mixte french / english
Main teacher:	Arezki Mokrani	
Learning objectives:	• Know and understand of the approximations used to determine the electronic structure of atoms. • Understand the action of an external field (electric, magnetic) on the electronic structure of an atom and the different electronic transitions in the presence of an electromagnetic filed • Know the spectroscopic notations and their meaning • Know the orders of magnitude in electronic, vibrational and rotational spectra of a molecule.	
Content covered:	Quantum theory of atoms. Hydrogen atom. Atoms with several electrons. Magnetism of atoms. Atoms in an external field. Interaction of an atom with an electromagnetic wave. Radiative transitions. Selection rules. Fine structure. Spectral terms. Introduction to molecular physics. Vibrational and rotational spectra.	
Teaching methods:	Lectures and exercises	
Prerequisites :	Basic knowledge in Physics and Physical Chemistry for a Bachelor student	

Elaboration of (nano)materials 1

TU: CHEMICAL SYNTHESIS (3 ECTS)

Coordination chemistry and électronics transistions

Affiliated TU : Chemical synthesis (3 ECTS)	
Duration: 12h	
Year/semester : M1/S1	Language: french
Main teacher:	Martine Bujoli-Doeuff
Learning objectives:	• Characterize an inorganic molecule or a solid by its absorption spectrum • Identify the nature of the electronic transition • Know the associated terminology
Content covered:	1. Crystal field theory with electronic correlation. 2. Electronic transitions and selection rules. 3. Application: characterization via UV-visible absorption spectra of various transition metal complexes
Teaching methods:	Lectures and tutorials
Bibliography :	« Chimie Inorganique », J.E. HUHEEY, E.A. KEITER et R.L. KEITER, De Boeck Université (2000) « Physico-Chimie Inorganique », S.F.A. KETTLE, De Boeck Université (1999) « Advanced Inorganic Chemistry », F.A. COTTON, G. WILKINSON, C.A. MURILLO, Wiley (1999) « Chemistry of the elements », second edition, N.N. GREENWOOD et A. EARNSHAW, Pergamon Press (1997) « Structure électronique des éléments de transition », O. KAHN, PUF (1977)
Prerequisites :	Quantum mechanics: undergraduate level. Fourier transform, analysis in the complex plane.

Inorganic condensation in aqueous solution

Affiliated TU : Chemical synthesis (3 ECTS)	
Duration: 8h	
Year/semester : M1/S1	Language: mixte french / english
Main teacher:	Rémi Dessapt
Learning objectives:	• Establish hydrolysis and neutralization 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 various atoms (or groups of atoms) in the molecule • Predict from the partial charges of the atoms the stability of a complex with respect to condensation and precipitation reactions in aqueous solution • Establish a structural relationship between the condensed species and the precursor in aqueous solution • Identify the nature of the reactions involved in the condensation of metal cations
Content covered:	1. introduction 2. Metal cations in aqueous solutions 3. The partial charge model 4. Condensation and precipitation of metal cations in aqueous solution
Teaching methods:	Lectures, tutorials and practical exercices

Introduction to inorganic molecular chemistry

Affiliated TU : Chemical synthesis (3 ECTS)		
Duration: 8h		
Year/semester : M1/S1		Language: french
Main teacher:	Hélène Serier-Brault	
Learning objectives:	The aim of this course is to provide a basic understanding of metal complexes..	
Content covered:	A: Introduction to transition metal complexes B: The crystal field model C: Stability of transition metal complexes	
Teaching methods:	Lectures and tutorials	

TU: MATERIALS PRODUCTION PROCESSES (3 ECTS)

Thin films

Affiliated TU : Materials production processes (3 ECTS)		
Duration: 16h		
Year/semester : M1/S2		Language: mix french / english
Main teacher:	Jérémy Barbé	
Learning objectives:	• Understanding the main fields of application and deposition technics of thin films, the surface mecanisms • Choose a technique of thin film deposition according to a given application. • Evaluate the evaporated or sputtered fux of atoms and able to estimate the deposition rate and the rate of contamination by residual gas	
Content covered:	Main fields of application of thin films Panorama of the techniques of thin film deposition. Surface mechanisms leading to the growth of a thin film Principle of the cathodic sputtering, the thermal evaporation, the chemical vapour deposition and atmospheric deposition techniques.	
Teaching methods:	One evaluation : DS	
Bibliography :	Thin films - R.A. Powell, S.M. Rossnagel - Academic Press	
Prerequisites :	Notions of thermodynamics: Maxwell-Boltzman distribution, Clapeyron law - Saturation vapor pressure - Notion of crystallography: Crystalline Bravais lattice	

Methodologies for (nano) materials synthesis

Affiliated TU : Materials production processes (3 ECTS)		
Duration: 20h		
Year/semester : M1-S2		Language: french
Main teacher:	Philippe Poizot	
Learning objectives:	The aim of this CE is to introduce various common synthesis routes (chemical and electrochemical) for the development of inorganic and hybrid organic-inorganic materials. At the end of this course, students will be able to: • Master the terminology related to different synthesis processes • Propose material development strategies based on a reasoned approach (using knowledge of thermodynamics, kinetics and electrochemistry). • Understand the relationship between a material's structure (size, morphology, dispersity) and the synthesis route used to design it	
Content covered:	1. Solid state synthesis (ceramic route): choice and shaping of reagents, atmosphere control, quenching atmosphere, quenching, crystal growth phenomena, sintering, grinding and the concept of mechanosynthesis. 2. Soft chemistry: after a presentation of the crucial parameters controlling the precipitation of inorganic inorganic solids (solvent, pH, temperature, precursors, condensation reactions, nucleation growth, template...), various synthesis processes will be discussed (synthesis by decomposition of coordination complexes, the Pechini process, solvothermal synthesis, polyol synthesis polyol synthesis, intercalation synthesis, sol-gel synthesis, self-assembly processes).	
Teaching methods:	Lectures and tutorials	

Materials characterization

TU: MATERIALS CHARACTERIZATION 1 (6 ECTS)

Signal acquisition and processing,

Affiliated TU : Materials characterization 1 (6 ECTS)		
Duration: 20h		
Year/semester : M1 / S1		Language: french
Main teacher:	Clément HUNEAU	
Learning objectives:	• Understand: operations on signals, the notion of noise color, the characteristics of analog filters, the notion of spatial filters • Predict qualitatively the spectrum of a signal (1D) or image (2D) • Numerically calculate Fourier transforms • Predict and avoid spectral aliasing • Use a digital filter • Load, represent and process signals in matlab language	
Content covered:	1 - Signal 2 - Spectrum 3 - Filter	
Teaching methods:	Lectures, tutorials and practical exercices	
Prerequisites :	Integral calculus Basis of programming	

Expérimental physics

Affiliated TU : Materials characterization 1 (6 ECTS)		
Duration: 15h		
Year/semester : M1 / S1		Language: mix french / english
Main teacher:	Patricia Bertoncini	
Learning objectives:	• Implement an experimental approach: follow a measurement, analyze experimental data, compare with a model, interpret the results, develop a synthesis • Read and apply a safety instruction • Clearly write a scientific report while respecting the conventions and specific rules of the discipline • Work independently and in a team	
Content covered:	Several experiments are proposed to deepen the knowledge and understanding of different aspects of solid-state physics and atomic and molecular physics.	
Teaching methods:	Practical work in team of two students / individual evaluation	
Bibliography :	Several documents describing the apparatus, the experiments to do, essential basic knowledge…	
Prerequisites :	Basic knowledge in Physics and Physical Chemistry for a Bachelor student	

Application of group theory

Affiliated TU : Materials characterization 1 (6 ECTS)	
Duration: 12h	
Year/semester : M1/S1	Language: french
Main teacher:	Aurelian Popa
Learning objectives:	• Know 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 (space vectors, atomic orbitals, atomic orbitals, chemical bonds); manipulate representative matrices • Reduce a representation into irreducible representations of the point group • Find Linear Combinations Adapted to Symmetry (CLAS) • Manipulate the Projection Operator and the Gram-Schmidt orthogonalization procedure • Define and identify the vibrational modes of a molecule • Construct and interpret a Molecular Orbital diagram
Content covered:	Operations and symmetry elements Point groups (definition, classification, identification) Stereographic projection of a point group Non-degenerate representations, matrix representations, degenerate representations, reduction in IR Direct sum, Direct product, Projection operator, Linear Combinations Adapted to Symmetry (CLAS), Orthogonalization of vector bases Applications of group theory to molecular vibrations (IR, RAMAN) and chemical bonds (Molecular Orbitals)
Teaching methods:	Lectures and tutorials

Cristallography and X-ray diffraction

Affiliated TU : Materials characterization 1 (6 ECTS)	
Duration: 20h	
Year/semester : M1/S1	Language: french
Main teacher:	Olivier Hernandez
Learning objectives:	• Manipulate 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 lattice and pattern to the diffraction pattern • Know the steps involved in structural resolution from a single-crystal diffraction pattern
Content covered:	Crystallography : - Direct/reciprocal gratings - 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 - Systematic extinction conditions - Experimental methods - Application of ab-initio structural resolution on single crystals
Teaching methods:	Lectures and tutorials, face-to-face and distance

TU: MATERIALS CHARACTERIZATION 2 (4 ECTS)

Optical and vibrational spectroscopies

Affiliated TU : Materials characterization 2 (4 ECTS)		
Duration: 23.30h		
Year/semester : M1/S2		Language: french
Main teacher:	Maxime Bayle	
Learning objectives:	• Formally describe vibration in a molecule and a solid, • Explain the concept of natural frequency of vibration, • Use experimental infrared absorption and Raman scattering techniques to excite and anlayze these vibrations, • Use their knowledge of group theory to count the modes of vibration of molecules and crystals, and anticipate their infrared and Raman activity. • Describe the operation of different lasers.	
Content covered:	1. Fundamentals of vibrational spectroscopy : Molecular and crystal dynamics - Light-matter interactions - Infrared and Raman spectroscopy 2. Introduction to lasers : History and mechanisms involved - Laser types and classification - Operation of various lasers (gas, solid-state, semiconductor) 3. Group theory applied to optical spectroscopy : Groups and symmetry operations - Character tables - Representation of atomic motions - Introduction to the study of crystals	
Teaching methods:	Lectures, tutorials and practical exercices	
Bibliography :	Spectroscopies vibrationnelles : Théorie, aspects pratiques et applications. Ouvrage collectif du Groupe French de Spectroscopie Vibrationnelle (GFSV), Guilhem Simon (2020)	

Impedance spectroscopy

Affiliated TU : Materials characterization 2 (4 ECTS)		
Duration: 16h		
Year/semester : M1/S2		Language: mixte french / english
Main teacher:	Caroline Borderon	
Learning objectives:	• Identify and formulate filter properties • Identify and differentiate physical properties associated with the Argand diagram (impedance spectroscopy)..	
Content covered:	We study the transfer functions of filters of different orders (gain and phase Bode diagrams). An analogy will then be drawn between electrical circuits and the physical characteristics of materials. 1. 1st-order and 2nd-order filters. Transfer function and Bode diagram 2. Impedance spectroscopy. Argand diagram. Modeling materials using simple electrical circuits. Debye model. Cole-Cole and Davidson-Cole model.	
Teaching methods:	Lectures and personal work : exercices, articles, etc	
Bibliography :	1. R. MacDonald, “Impedance spectroscopy,Theory, Experiment and Application”, Wiley (2005). 2. R. Coelho, B. Aladenize, « Les diélectriques, propriétés diélectriques des matériaux isolants », Traité des nouvelles technologies Série matériaux, Hermes (1993).	

Cristallography and DRX2

Affiliated TU : Materials characterization 2 (4 ECTS)	
Duration: 4h	
Year/semester : M1 S2	Language: french
Main teacher:	Hélène Serier-Brault
Learning objectives:	• Provide practical exercises in X-ray powder diffraction
Content covered:	- Diagram indexing - Cell parameter refinement - Modeling a powder diffraction pattern
Teaching methods:	Pair work in the computer room
Prerequisites :	Prerequisites are the objectives of UE M1 E-MAT - Crystallography and X-ray diffraction.

Properties of materials & systems for energy

TU: PROPERTIES OF MATERIALS 1 (4 ECTS)

Solid state physics

Affiliated TU : Properties of materials 1 (4 ECTS)	
Duration: 32h	
Year/semester : M1, semestre 1	Language: French
Main teacher:	Jean-Luc Duvail
Learning objectives:	• To know, understand and apply the fundamental concepts of physical properties of crystalline materials as well as the correlation between crystal structure, electronic or phononic structure and electrical, optical and thermal properties, even mechanical ones. These properties are the functions operated in devices and systems of multiple application domains. This course is the base for all modules related to functional materials and energy at a more advanced level in M1 and M2.
Content covered:	Introduction Reminders: Crystal Structures – Reciprocal Networks Part A: Vibronic structure, phonons and associated properties 1. Vibrations and phonons in solids 2. Thermal properties due to phonons 3. Optical properties related to phonons Part B: Electronic structure and associated properties 1. Fermi free electron gases – metal properties 2. Near-free electrons – energy bands – transition metal properties 3. Semiconductors, insulators and semi-metals Part C: pn junction and metal/semiconductor contact: toward electronic components 1. Out-of-balance semiconductors 2. Junction pn 3. Metal/semiconductor contact
Teaching methods:	Reverse pedagogy: preparation of the course in autonomy. In class, discussion on important concepts; application exercises.
Bibliography :	C. R. Kittel, Introduction to solid-state physics 8th ed. ISBN: 978-1-119-45416-8 N. Ashcroft, N. D. Mermin, Solid state physics ISBN: 0-03-083993-9
Prerequisites :	Electromagnetism – Newtonian mechanics - Thermodynamics - Statistical physics - Quantum physics

Electronic structure of solids

Affiliated TU : Properties of materials 1 (4 ECTS)	
Duration: 12h	
Year/semester : M1/S1	Language: mixte french / english
Main teacher:	Jean Le Bideau
Learning objectives:	• Qualitatively interpret an electronic structure diagram of a solid. • Understand the possible effects of anisotropies in crystallographic or electronic structures.
Content covered:	1. Reminders - General 2. Structural description 3. The electronic structure of solids Practical examples: TiS2 and TiO2, graphite and diamond: crystallographic structures, electronic structures, properties

Teaching methods:	Lectures and personal studies on articles
Bibliography :	Introduction à la physique des solides - C. Kittel Intruduction à la chimie du solide - L. Smart & E. Moore Basic solid state chemistry - A. R. West Electronic structure of solids - E. Canadell, M.-L. Doublet, C. Iung

TU: HEAT TRANSFERT AND ELECTROCHIMIC CHARGE TRANSFER (5 ECTS)

Electrochemistry - level 1

Affiliated TU : Heat transfert and electrochimic charge transfer (5 ECTS)		
Duration: 12h		
Year/semester : M1-S1		Language: French
Main teacher:	Mohammed Boujtita	
Learning objectives:	The aim of electrochemistry teaching (level 1) is to reinforce the basic concepts needed to tackle charge transfer reactions at the electrode/solution interface and material transport phenomena in the electrolyte. At the end of this course, students should be able to: • Mastering the various aspects of an electrochemical reaction • Predict the influence of electrolyte solution and electrode material on the electrochemical behavior of an electroactive species.	
Content covered:	1. Electrochemical process, concepts of potential and current 2. Electron transfer reactions at the electrode/electrolyte solution interface 3. Butler-Volmer equation, Tafel empirical law, determination of kinetic parameters (α and k°) of an electrochemical reaction 4. Mass transport: diffusion, convection, and migration 5. Amperometric techniques with controlled potential, cyclic voltammetry in convective (stationary) and diffusion regimes, chronoamperometry, and chronocoulometry.	
Teaching methods:	Classroom courses and tutorials	
Bibliography :	Electrochemical Methods: Fundamentals and Applications, J. Allen Bard / Larry R. Faulkner	
Prerequisites :	Electrokinetics, redox in aqueous solution (thermodynamic approach and Nernst equation), galvanic cell	

Electrochemistry - level 2

Affiliated TU : Heat transfert and electrochimic charge transfer (5 ECTS)		
Duration: 18h		
Year/semester : M1-S1		Language: French
Main teacher:	Philippe Poizot	
Learning objectives:	The aim of this course is to deepen the basic concepts of electrochemistry by introducing electrochemical generators, solid-state electrochemical reactivity (contextualized within the framework of electrochemical generator development) and advanced techniques in analytical electrochemistry. At the end of this course, students should be able to: • Describe the main electrochemical generators and their operating modes • Identify the electrical performance criteria of common batteries and accumulators	

	• Propose a protocol for analyzing a complex sample and identify the chemical and electrochemical processes involved
Content covered:	<u>Part Electrochemical generators</u> 1. Global energy context 2. From redox to electrochemical reactions 3. Thermodynamics - electromotive force at equilibrium (I=0) 4. Kinetic aspect - non-equilibrium electromotive force (I≠0) 5. Characteristic quantities 6. Electrochemical insertion (intercalation) 7. Cell and battery geometries 8. Electrochemical cell characterization 9. Examples of non-rechargeable systems (batteries) 10. Examples of rechargeable systems (accumulators - batteries) <u>Electrochemical kinetics and analytical part</u> 1. Analytical electrochemistry of complex media 2. EC', ECE, ECEC mechanisms 3. Advanced electrochemical techniques (Pulse methods)
Teaching methods:	Classroom courses, tutorials, and labwork
Bibliography :	
Prerequisites :	Electrochemistry level 1

Engineering heat transfer

Affiliated TU : Heat transfert and electrochimic charge transfer (5 ECTS)		
Duration: 24h		
Year/semester : M1-S1		Language: English
Main teacher:	Xavier PY	
Learning objectives:	• Know and formalize the fundamental mechanisms of heat transfer • Know the key heat transfer properties of materials • Identify the heat transfer mechanisms involved in a system, describe their coupling and quantify their contributions • Draw up heat balances for steady-state and transient systems	
Content covered:	The objective of the course is to master the different fundamental heat transfer mechanisms (conduction, convection, radiation) as well as their possible couplings, in single or multiphase systems, with or without change of state or chemical reaction, in order to establish heat balances under steady state as well as under transient state. The tutorials are illustrations of these transfers applied to different types of materials (homogeneous, heterogeneous, composite, anisotropic...) in the context of energy processes dedicated to the energy transition (in particular renewable energies).	
Teaching methods:	Classroom courses and tutorials	
Bibliography :	Fundamentals of Heat and Mass Transfer. Theodore L. Bergman, Adrienne S. Lavine, Frank P. Incropera, David P. DeWitt, Wiley, 2016, ISBN : 1118989171, 9781118989173.	
Prerequisites :		

TU: PROPERTIES OF MATERIALS 2 (3 ECTS)

Properties of materials 2

<table>
<tr><td colspan="3">Affiliated TU : Properties of materials 2 (3 ECTS)</td></tr>
<tr><td colspan="3">Duration: 21.30h</td></tr>
<tr><td colspan="2">Year/semester : M1/S2</td><td>Language: mixte french / english</td></tr>
<tr><td>Main teacher:</td><td colspan="2">Benoit GUIFFARD</td></tr>
<tr><td>Learning objectives:</td><td colspan="2"><u>Dielectric properties section</u>
• Understand the origin of different polarization mechanisms and model them
• Relate these mechanisms to resonance and relaxation processes
• Understand the coupling between an electromagnetic wave and polarization
• Understand the Lyddane Sachs Teller relation, the notion of the polaron and its importance for charge transport in insulators
• Understand the origin of piezoelectric and pyroelectric properties
• Understand ferroelectricity and its origins, the organization of ferroelectric domains, and what a ferroelectric domain wall represents.
• Understand the concepts of coercive fields and remanent polarization
• Some applications of dielectric properties

<u>Magnetic properties section</u>
• Recognize a paramagnetic, diamagnetic or ferromagnetic material from measurements of M(H) magnetization cycles
• Know the orders of magnitude of the main magnetic quantities for ferromagnetic metals: susceptibility, magnetization, coercive/saturation fields
• Explain the mechanisms responsible for the various forms of magnetism at the atomic scale
• Explain the origin of itinerant ferromagnetism, the notion of soft/hard magnetic materials and magnetic anisotropies
• Explain the effect of temperature on the magnetic behavior of a material
• Identify whether a material is superconducting
• Explain the link between property and function of use

<u>Piezo/flexoelectric materials: properties and applications</u>
• Understand the various electromechanical coupling mechanisms in matter, the different families of piezoelectric materials and the classic devices incorporating them
• Handle the macroscopic constitutive equations of piezo- and flexo-electricity
• Learn about figures of merit (between dielectric/mechanical/piezoelectric coefficients) for sensor/actuator applications
• Determine piezoelectric and flexoelectric coefficients from device characteristics and vice versa</td></tr>
<tr><td>Content covered:</td><td colspan="2"><u>Part Dielectric properties</u>
1. Polarization mechanisms - Dielectric relaxation.
2. Optical properties of dielectrics.
3. Transport in insulating media.
4. Piezoelectricity, pyroelectricity.
5. Ferroelectric materials.

<u>Part Magnetic properties</u>
1. Magnetic states of matter
2. Ferromagnetic metals
3. Magnetic oxides
4. Introduction to superconducting materials

<u>Piezo/flexoelectric materials: properties and applications</u></td></tr>
</table>

	1 -Perties of piezoelectric materials. Types and applications 2 -Piezoelectric transducers in the static or quasi-static regime 3. Flexoelectricity
Teaching methods:	Lectures and tutorials
Prerequisites :	Electromagnetism L3, Solid state physics L3

Modeling

TU: MODELING (5 ECTS)

Semi-classical description of atomic interactions

Affiliated TU : Modeling (3 ECTS)	
Duration: 15 h	
Year/semester : M1/S	Language: mixte french / english
Main teacher:	Yann Claveau
Learning objectives:	• Implement a molecular dynamics study of a fluid: from system creation to trajectory analysis to deduce fluid properties • Model physical phenomena using the kinetic Monte Carlo method
Content covered:	- Semi-classical intra- and intermolecular interactions - Molecular dynamics - Kinetic Monte Carlo - Thermodynamic assemblies - LAMMPS - Python - parallel computing
Teaching methods:	Cours / TP en salle informatique évaluation sur 1 TP et 1 projet En fonction du projet choisi, le travail peut être ensuite publié.
Bibliography :	Computer simulation of liquids – Tildesley Statistical mechanics : theory and molecular simulation – Tuckerman – Computer Simulation Using Particles – RW Hockney & JW Eastwood – Adam Hilger Hanbook of Monte-Carlo Methods – Dirk P. Kroese, Thomas Taimre, Zdravko I. Botev, - Wiley
Prerequisites :	Base en programmation python (calcul scientifique de base + utilisation de fonctions), Linux, bases de thermodynamique

Data processing

Affiliated TU : Modeling (3 ECTS)	
Duration: 5.30h	
Year/semester : M1/S2	Language: french
Main teacher:	Clément Huneau
Learning objectives:	• Understand multivariate probability distributions and the notion of covariance • Understand the concept of estimator and bias-variance trade-offs • Model and solve classical data analysis problems
Content covered:	1/ Signal/random vector 2/ Linear observation model

	3/ Parametric estimation (adjustment) 4/ Classification
Teaching methods:	Interactive, illustrated course and hands-on exercises
Bibliography :	Candelpergher, Bernard. 2013. *Théorie des probabilités. Une introduction élémentaire*. Mathématiques en devenir. Paris: Calvage et Mounet.

Physical and multi-scale modeling

Affiliated TU : Modeling (3 ECTS)	
Duration: 18 h	
Year/semester : M1 / S2	Language: mixte french / english
Main teacher:	Stéphane Cuenot
Learning objectives:	At the end of this UE, the student will be able to: • Master the modeling steps of a physical problem • Master the convergence of a numerical solution according to the mesh • Know the different modeling steps of a physical problem
Content covered:	The content is as follows: - Introduction to numerical resolution by finite elements - 2D and 3D modeling of simple and complex physical problems - Resolution steps: drawing, boundary conditions, meshing, solver, post-processing, analysis - Mesh control, convergence of the numerical solution, mesh-computation time relationship - Mesh optimization for a given problem - Choice of numerical study (stationary, transient, parametric, frequency...) and the appropriate solver - Post-processing of numerical results The physical problems addressed will mainly cover the fields of solid mechanics, heat transfer, fluid mechanics, electromagnetism and transport of diluted species
Teaching methods:	Lectures, tutorials and practical assignments before modeling projects in pairs

Reversed problem

Affiliated TU : Modeling (3 ECTS)	
Duration: 9.30h	
Year/semester : M1/S2	Language: mix french / english
Main teacher:	Clément Huneau
Learning objectives:	• Understand ill-posed problems and the need for regularization • Use an algorithm to optimize an estimation criterion • Regularize the criterion of an inverse problem using a priori information
Content covered:	1/ Introduction Direct/inverse model Source separation, Tomography, Deconvolution Characterization or mapping? 2/ Ill-posed problems Conditioning Error propagation 3/ Regularization Bias/Variance trade-off Quadratic

	Parcimonious
Teaching methods:	Interactive, illustrated course and hands-on exercises
Bibliography :	Idier Jérôme. 2001. Approche bayésienne pour les problèmes inverses. Hermes Science Publications. IC2 Signal et Image. Lavoisier.
Prerequisites :	

Preparing for professional integration

TU: PREPARING FOR PROFESSIONAL INTERGRATION 1 (4 ECTS)

Foundations of organisations

Affiliated TU : Preparing for professional integration 1 (4 ECTS)	
Duration: 16h	
Year/semester : M1/S1	Language: mixte french / english
Main teacher:	To be defined
Learning objectives:	• Describe an organization • Identify an organizational problem • Develop a critical and reflective perspective on the world of organisations
Content covered:	Introduction to the managerial and economic challenges of organizations, enabling students to understand and define what an organizational problem is. Students will develop theoretical and practical foundations for understanding the variety of organizations, as well as the main principles that make them up. We will also address the major issues of contemporary organization in relation to several organizational dimensions: culture, power, decision-making methods, the place and role of incentives and management tools, and strategy. Examples, readings of articles (press, research, specialized magazines) and case studies (paper, film, series) will be used to address these different themes.
Bibliography :	*Théorie des Organisations (A. Desreumaux),* Editions EMS: 2015 (3eme ed) Organization Theory: Challenges and perspectives. Mc Aulay et al. (2007) Pearson *Mintzberg on management : inside our strange world of organizations (H. Mintzberg), [Le management; Voyage au centre des organisations,* Free Press [Eyrolles Ed. d'Organisation]

Experimental project 1

Affiliated TU : Preparing for professional integration 1 (4 ECTS)	
Duration: 20 h	
Year/semester : M1S1	Language: french
Main teacher:	Jean-Luc Duvail, Philippe Poizot
Learning objectives:	• Know the approach and some appropriate tools to conduct a bibliographic research in the field of physics and chemistry • Knowing the main principles of scientific integrity and the notion of plagiarism • Knowing the expectations of a scientific report and an oral presentation support
Content covered:	1. Research and management of scientific and technological information (STI) From the laboratory notebook to publications, to patent filing Training in querying and the proper use of specialized databases (Scifinder, Science Direction, GoogleScholar,...) Use of a STI management tool (Zotero) 2. Scientific communication Main principles of scientific integrity and notion of plagiarism; discovery of the software Compilatio Rules and principles for the formatting of a scientific document Design and oral presentation of a scientific communication
Teaching methods:	Combination of lectures, personal preparatory work, implementation in class (on L3 internship reports) and on a computer. Evaluation: Bibliographic report in English

Bibliography :	Scientific integrity – Anti-plagiarism charter of Nantes University: https://www.univ-nantes.fr/recherche-et-innovation/laboratoires/lintegrite-scientifique-un-engagement-de-luniversite-de-nantes

Thématic school

Affiliated TU : Preparing for professional integration 1 (4 ECTS)		
Duration: sans objet		
Year/semester : M1/S1		Language: french
Main teacher:	Jean-Luc Duvail, Philippe Poizot, Xavier Py	
Learning objectives:	• Manage the organization of the day(s) related to the event. • Develop interpersonal skills through interactions with event guests. • Strengthen the ability to work independently.	
Content covered:	Variable topics	
Teaching methods:	Event project	

TU: PREPARING FOR PROFESSIONAL INTERGRATION 2 (6 ECTS)

Chemical risks

Affiliated TU : Preparing for professional integration 2 (6 ECTS)		
Duration : 4h		
Year/semester : M1/S2		Language: french
Main teacher:	Virginie Blot	
Learning objectives:	• Identify the health & safety risks he/she will face in his/her professional life, • Identify ways of preventing the risks he/she will face in his/her professional life.	
Content covered:	This intervention raises students' awareness of health and safety risk management in the chemical laboratory or, more generally, in their future professional activity. It should also help them validate the CNRS NEO self-training module, mandatory for all new entrants to a CNRS research laboratory.	
Teaching methods:	Distance learning will enable students to follow the INRS e-learning course on chemical risks, "Acquérir les notions de base sur les produits chimiques". The face-to-face session will introduce students to the risks they will face in their future working lives.	

Introduction to project management

Affiliated TU : Preparing for professional integration 2 (6 ECTS)		
Duration : 8h		
Year/semester : M1/S2		Language: mixte french / english
Main teacher:	Mathias Guérineau	
Learning objectives:	• Describe an organization • Identify an organizational problem • Take a reflective, critical look at the world of organizations • Describe a project • Organize a project • Define and implement management practices	

Content covered:	Students will have two introductory elements, one focusing on organization theory and the other on project management: I1 orga Introduction to the managerial and economic issues of organizations, enabling students to understand and define what an organizational problem is. Theoretical and practical foundations for understanding the variety of organizations, as well as the main principles on which they are based. Major issues of contemporary organization in relation to several organizational dimensions: culture, power, decision-making methods, place and role of incentives and management tools, strategy. I2 projet Introduction to project management: definitions of project management, presentation of the specificities of project activity within organizations, fundamental principles of project management: defining objectives, planning tasks, communicating internally and externally, etc.
Teaching methods:	Face to faceteaching : reading articles, case studies, etc., group project
Bibliography :	*Théorie des Organisations (A. Desreumaux),* Editions EMS: 2015 (3eme ed) Organization Theory: Challenges and perspectives. Mc Aulay et al. (2007) Pearson *Mintzberg on managment: inside our strange world of organizations (H. Mintzberg), [Le management; Voyage au centre des organisations,* Free Press [Eyrolles Ed. d'Organisation] 1989 [1998] *Management de projet,* Garel, G. (2011).. La découverte collection *Repères*, Antimanuel de management de projet : composer avec les incertitudes, Thomas Reverdy, 2021, Dunod Pratiques de management de projet ; 46 outils et techniques pour prendre la bonne décision, Vincent Drecq, 2020, Dunod

Experimental project 2

Affiliated TU : Preparing for professional integration 2 (6 ECTS)	
Duration : sans objet	
Year/semester : M1S1	Language: French
Main teacher:	Jean-Luc Duvail, Philippe Poizot
Learning objectives:	• Integrate a research or R&D activity • Manage a project according to deadlines. • Develop soft skills in contact with laboratory professionals • Put into practice the concepts addressed in the EC Experimental Project 1 • Implement adapted experiments to respond to a questioning • Use laboratory equipments after a training period • Develop ability to work independently • Format and analyze results • Write a weekly progress report • Present works in English during an oral defense
Content covered:	Alone or in pairs, from January to March, each student integrates a research project under the supervision of a researcher/teacher-researcher. He/She discovers a field of research or R&D, mobilizes the concepts seen in his/her university curriculum, particularly at the M1 level, understands techniques and research equipment to fabricate a (nano, micro)material and characterize it. He/She must record all his/her studies (laboratory notebook) to prepare a weekly report that he/she submits to his/her supervisor. He/She proposes an analysis of the results obtained, based where appropriate on previous articles or reports.

	He/She must establish a retro-planning and a detailed plan for the oral presentation medium that he submits to his supervisor in compliance with the specifications and deliverables. This presentation must include a section on the context of the theme and the team's activity, then a summary with analysis of the results obtained. The oral defense is conducted in English.
Teaching methods:	Teaching by project – immersion in a research laboratory – integration of an experimental research project
Bibliography :	Scientific integrity – Anti-plagiarism charter of Nantes University: https://www.univ-nantes.fr/recherche-et-innovation/laboratoires/lintegrite-scientifique-un-engagement-de-luniversite-de-nantes

TU: INTERNSHIP (9 ECTS)

The internship plays an important role in the E-Mat Master's programme and is based on close interaction between research and technological innovation. Students will spend between 2 and 4 months working in a national or international research team or in industry

Duration : From 2 to 4 month	ECTS : 9	
Year/semester : M1 / S2		Language: french/english
Referent teachers :	Patricia Bertoncini and Philippe Moreau	
Learning objectives:	• Implement a scientific approach in an individual research work • Join a team in a professional environment • For internships abroad, achieve a true cultural and linguistic immersion	
Content covered:	Research themes in the fields of functional materials, associated processes and energy.	

Mobility for students enrolled in the E-Mat Master's programme during the work placement:

This programme encourages international mobility for students by making available to them the international network of teacher-researchers from the two partner laboratories.

Students receive a mobility grant of €500 to €700 per month, depending on the country of destination. They may also receive a €1,000 relocation grant.

Hosting foreign students for work placements in our partner laboratories:

Foreign students wishing to undertake a work placement in one of our partner laboratories should send their application, together with their CV and a summary of their interests, to the programme coordinators. If the application is accepted, they will be invited to an interview to explain their objectives.

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