PHYSICS OF MOLECULES AND MATERIALS

Master de Physique Fondamentale et Applications

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PRESENTATION

The ***Physics of Molecules and Materials*** track of the ***Lille Master's in Fundamental Physics and Applications*** aims to train physicists to tackle the major scientific questions of the 21st century, concrete and applied issues such as the design of new materials for the industry of tomorrow that are more compatible with the environmental and energy challenges of our time; to fundamental questions such as the behavior of matter within planets and atmospheres, methods of calculation at the atomic scale, and the use of large international research instruments.

The training will be of interest for two types students:

- students in ***search of solutions***, who will be trained in the latest advances in materials science, enabling them to develop and exploit new materials, the latest analytical methods, and analytical tools to address today's societal issues (energy transition, energy efficiency, recycling, etc.) from the perspective of materials physics.
- students in ***search of discoveries***, who will be able to draw on their training to understand the future of materials in various environments and conditions, from the heart of a nuclear power plant to polymers, metals, pharmaceutical materials, and even the interior of planets or the atmosphere.

The program is part of the University of Lille's Graduate Program ***Materials for a Sustainable Future***, which aims to train scientists to tackle the major challenges associated with the transitions currently underway through materials science. It is also associated with the Erasmus Mundus BIOPHAM program, which offers training in materials science dedicated to pharmaceutical applications and with which it shares approximately 50% of its courses.

In order to welcome students from all backgrounds and prepare them to work in a European and international context, the language of instruction is English. The teachers are French-speaking and able to answer questions and interact in French, but the courses are taught in English.

Website of the master program: https://master-physique.univ-lille.fr
Person in charge and contact: Sébastien MERKEL, sebastien.merkel@univ-lille.fr

ORGANIZATION IN TEACHING BLOCS (BCC)

The ***Physics of Molecules and Materials track*** is organized into two years and four semesters of 30 credits each, with classes and internships from September to June or July, for a total of 120 ECTS credits.

In order to welcome students from all backgrounds and prepare them to work in a European and international context, the language of instruction is English. The majority of teachers are French-speaking and able to answer questions and interact in French, but the courses are taught in English.

The courses are structured into three teaching blocks (Bloc de Compétence et Connaissance BCC) described below:

- BCC1: Implementing fundamental physics tools and approaches to produce highly specialized knowledge
- BCC2: Producing and communicating highly specialized knowledge, including in a professional context
- BCC3: Solving complex problems by applying fundamental physics concepts

Each BCC is developed over the four semesters of the program.

BCC1: IMPLEMENTING FUNDAMENTAL PHYSICS TOOLS AND APPROACHES TO PRODUCE HIGHLY SPECIALIZED KNOWLEDGE

By implementing advanced and specialized uses of digital tools
By analyzing data for fundamental physics
By practicing an experimental approach adapted to a physics problem
By mobilizing and producing highly specialized knowledge

MASTER 1

Essential learning outcomes:

Level of development
Interpret measurement results and observations made during physical experiments and provide estimates of their uncertainties.
Program digital tools to process physical measurements in a relevant manner (possibly using machine learning or AI approaches).

Level of autonomy
Carry out experimental measurements in physics by proposing appropriate and, where applicable, innovative strategies.
Identify digital applications and the impact of their development in materials physics.
Develop a critical awareness of knowledge in a field and/or at the interface of several fields.

SEMESTER S1

- **AI and advanced computational methods in physics** – 3 ECTS
- **Atomic scale modeling I** – 3 ECTS
- **States of Matter and Materials Science Primers** – 3 ECTS

SEMESTER S2

- **Satellites and remote sensing** – 3 ECTS
- **Radiative transfer and radiation-matter interactions** – 3 ECTS
- **Large scale research infrastructures** – 3 ECTS
- **Experimental project** – 3 ECTS

MASTER 2

Essential learning outcomes:

Level of development
Develop and conduct complex experiments using high-tech equipment
Conduct research and scientific studies in materials and molecular physics

Level of autonomy
Use advanced digital tools for materials and molecular physics independently
Propose a robust experimental protocol adapted to a complex problem in materials and molecular physics

SEMESTER S3

- **Structural properties of matter : electron microscopy and diffraction** – 3 ECTS

- **Atomic scale modeling II** – 3 ECTS
- **Advanced Spectroscopy of Molecular Systems: From Gas Phase to Condensed Matter (ASMS)** – 3 ECTS

BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT

By mobilizing and producing highly specialized knowledge
By implementing specialized communication for knowledge transfer
By contributing to transformation in a professional context

MASTER 1

Essential learning outcomes:

Level of development
Communicate for training or knowledge transfer purposes, orally, in at least one foreign language
Analyze own actions in professional situations, self-assess to improve own practice as part of a quality approach

Level of autonomy
Mobilize highly specialized knowledge, some of which is at the forefront of knowledge in a field of work or study, as a basis for original thinking
Identify, select, and critically analyze various specialized resources to document a subject and synthesize this data for further exploitation

SEMESTER S1

- **Foreign language (pick 1 out of 2)** – 3 ECTS
  - *French*
  - *English*
- **PE or Graduate Program** – 3 ECTS
- **Tutored trainings** – 3 ECTS

SEMESTER S2

- **Internship** – 6 ECTS
- **Tutored trainings** – 3 ECTS

MASTER 2

Essential learning outcomes:

Level of development
Communicate for training or knowledge transfer purposes, both orally and in writing, in a foreign language.
Manage complex, unpredictable professional or academic contexts that require new strategic approaches.
Respect the principles of ethics, professional conduct, and social and environmental responsibility.
Supervise and carry out research and scientific studies in physics.
Promote and disseminate the results of studies in physical sciences (technical and scientific reports, patent files) within the company and to the scientific community.

> *Level of autonomy*
> *Develop critical awareness of knowledge in a field and/or at the interface of several fields*
> *Lead a project (design, management, team coordination, implementation and management, evaluation, dissemination) that may require multidisciplinary skills in a collaborative setting*
> *Analyze the technical, environmental, societal, and scientific challenges of projects involving physical phenomena and propose strategies that take into account their potential applications*

SEMESTER S3

- **Foreign language (pick 1 out of 2)** – 3 ECTS
  - *French*
  - *English*
- **Speciality (pick 3 out of 5)** – 2 ECTS EACH
  - *Materials under extreme conditions*
  - *Metals and alloys*
  - *Polymers*
  - *Mathematical crystallography*
  - *Instrumentation in spectroscopy*

SEMESTER S4

- **PE or Graduate Program** – 3 ECTS
- **Internship** – 27 ECTS

BCC3: SOLVING COMPLEX PROBLEMS BY APPLYING FUNDAMENTAL PHYSICS CONCEPTS

By mobilizing and producing highly specialized knowledge
By solving complex problems using fundamental concepts of fundamental physics

MASTER 1

Essential learning outcomes:

Level of development
Model complex physical phenomena using successive approximations and decompositions
Develop predictive tools based on valid models describing complex physical problems

Level of autonomy
Select relevant models and theories to address a problem

SEMESTER S1

- **Continuum mechanics** – 3 ECTS
- **Statistical physics and critical phenomena** – 3 ECTS
- **Condensed matter I – Electrons** – 3 ECTS
- **Atomic physics** – 3 ECTS
- **Remédiation** – 0 ECTS

SEMESTER S2

- **Condensed Matter II – Phonons** – 3 ECTS
- **Fundamentals of molecular spectroscopy** – 3 ECTS
- **Microstructures and defects in materials** – 3 ECTS

MASTER 2

Essential learning outcomes:

Level of development
Solving problems to develop new knowledge and procedures in materials and molecular physics
Integrating knowledge from different fields

Level of autonomy
Develop critical awareness of knowledge in a field and/or at the interface of several fields
Identify the limitations of models and theories used to address a complex problem

SEMESTER S3

- **Advanced thermodynamics and phase transformations** – 3 ECTS
- **Molecular mobility and amorphous state of matter** – 3 ECTS
- **From macro to nanophysics** – 3 ECTS
- **Materials plasticity** – 3 ECTS

ORGANIZATION IN SEMESTERS

The first year is divided into two semesters, with classes

- from September to December for the first semester;
- from January to the end of April for the second semester;
- a two-month internship in May and June (which may be extended into July and August).

The second year is divided into two semesters, with

- classes from September to January;
- a five-month internship starting at the end of January and ending at the end of June (which may be extended into July and August).

The program is based on traditional teaching in the form of lectures and tutorials, project-based teaching, and practical work, both digital and instrumental. Students also have the opportunity to work directly on research equipment, such as spectrometers and electron microscopes.

SEMESTER S1

- BCC1: IMPLEMENTING FUNDAMENTAL PHYSICS TOOLS AND APPROACHES TO PRODUCE HIGHLY SPECIALIZED KNOWLEDGE
  - **AI and advanced computational methods in physics** – 3 ECTS
  - **Atomic scale modeling I** – 3 ECTS
  - **States of Matter and Materials Science Primers** – 3 ECTS

- BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT
  - **Foreign language (pick 1 out of 2)** – 3 ECTS
    - *French*
    - *English*
  - **PE or Graduate Program** – 3 ECTS
  - **Tutored trainings** – 3 ECTS

- BCC3: SOLVING COMPLEX PROBLEMS BY APPLYING FUNDAMENTAL PHYSICS CONCEPTS
  - **Continuum mechanics** – 3 ECTS
  - **Statistical physics and critical phenomena** – 3 ECTS
  - **Condensed matter I – Electrons** – 3 ECTS
  - **Atomic physics** – 3 ECTS
  - **Remédiation** – 0 ECTS

SEMESTER S2

- BCC1: IMPLEMENTING FUNDAMENTAL PHYSICS TOOLS AND APPROACHES TO PRODUCE HIGHLY SPECIALIZED KNOWLEDGE
  - **Satellites and remote sensing** – 3 ECTS
  - **Radiative transfer and radiation-matter interactions** – 3 ECTS
  - **Large scale research infrastructures** – 3 ECTS
  - **Experimental project** – 3 ECTS

- BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT
  - **Internship** – 6 ECTS
  - **Tutored trainings** – 3 ECTS

- BCC3: SOLVING COMPLEX PROBLEMS BY APPLYING FUNDAMENTAL PHYSICS CONCEPTS
  - **Condensed Matter II – Phonons** – 3 ECTS
  - **Fundamentals of molecular spectroscopy** – 3 ECTS
  - **Microstructures and defects in materials** – 3 ECTS

SEMESTER S3

- BCC1: IMPLEMENTING FUNDAMENTAL PHYSICS TOOLS AND APPROACHES TO PRODUCE HIGHLY SPECIALIZED KNOWLEDGE
  - **Structural properties of matter : electron microscopy and diffraction** – 3 ECTS
  - **Atomic scale modeling II** – 3 ECTS
  - **Advanced Spectroscopy of Molecular Systems: From Gas Phase to Condensed Matter (ASMS)** – 3 ECTS

- BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT
  - **Foreign language (pick 1 out of 2)** – 3 ECTS
    - *French*
    - *English*
  - **Speciality (pick 3 out of 5)** – 2 ECTS EACH
    - *Materials under extreme conditions*
    - *Metals and alloys*
    - *Polymers*
    - *Mathematical crystallography*
    - *Instrumentation in spectroscopy*

- BCC3: SOLVING COMPLEX PROBLEMS BY APPLYING FUNDAMENTAL PHYSICS CONCEPTS
  - **Advanced thermodynamics and phase transformations** – 3 ECTS
  - **Molecular mobility and amorphous state of matter** – 3 ECTS
  - **From macro to nanophysics** – 3 ECTS
  - **Materials plasticity** – 3 ECTS

SEMESTER S4

- BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT
  - **PE or Graduate Program** – 3 ECTS
  - **Internship** – 27 ECTS

CLASSES IN SEMESTER S1

List of acronyms:

- BCC: Bloc de Compétence et Compétence = teaching block
- UE: Unité d’Enseignement = teaching unit
- CM: Cours magistral = main class
- TD: Travaux Dirigés = practicals
- C-TD: Cours-TD = mix of classes and practicals
- TP: Travaux Pratiques = labs

AI AND ADVANCED COMPUTATIONAL METHODS IN PHYSICS

UE : AI AND ADVANCED COMPUTATIONAL METHODS IN PHYSICS

BCC1: IMPLEMENTING FUNDAMENTAL PHYSICS TOOLS AND APPROACHES TO PRODUCE HIGHLY SPECIALIZED KNOWLEDGE

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Quentin Coopman* – quentin.coopman@univ-lille.fr
List of potential teachers: Quentin Coopman, Jérôme Riedi

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**10**		**15**		**25**

Required prior teaching unit(s):

Suggested readings:

1.

Syllabus :

Explore the intersection of AI, Machine Learning, and Physics in this class. Gain hands-on experience with cutting-edge techniques and applications tailored for the world of physics.

Objectives :
This class introduces AI and Machine Learning, focusing on their applications in physics. It covers fundamental concepts like supervised and unsupervised learning, regression, and classification, as well as advanced topics such as neural networks and deep learning. Students will explore classification techniques, clustering algorithms, and data preprocessing methods tailored for physics data. The course also delves into dimensionality reduction and advanced subjects like physics-informed machine learning. By the end, students will be equipped to apply AI and ML techniques effectively in the field of physics.

Course outline

- Courses (10H):
  - I - Introduction to Artificial Intelligence and Machine Learning (1H)
    - Overview of AI and ML
    - Applications in physics
    - Key concepts and terminology
  - II - Fundamentals of Machine Learning (1H)
    - Supervised vs. unsupervised learning
    - Regression, classification, prediction
    - Evaluation metrics

- III - Classification/Clustering algorithms (1H30)
  - Linear Models and Regularization (Linear regression)
  - Decision Trees and Ensemble Methods (Decision trees, Random, Gradient boosting regression tree forests)
  - K-means
- IV - Dimensionality reduction (e.g., Principal Component Analysis) (45 mins)
- V - Neural Networks and Deep Learning (2H15)
  - Introduction to neural networks
  - Activation functions
  - Training neural networks
  - Encodeur/Decodeur
- VI - Data Preprocessing (1H)
  - Handling physics data
  - Feature selection and extraction
  - Data normalization and scaling
  - Datacentric methods
- VII - Introduction Advanced Topics in Machine Learning for Physics (2H)
  - Physics-informed machine learning
  - Interpretable AI models

- Practicals (15H):
  - The practical sessions (TDs/TPs) will be conducted with the assistance of the CRI and the MesoNET program to access the notebooks. The practical sessions will cover the themes discussed in the lecture courses, namely:
    - Linear models (3H)
    - K-means (2H)
    - Principal Component Analysis (2H)
    - Neural Networks (3H)
    - Deep Learning (3H)
    - Data Preprocessing (2H)

Skills acquired

- Grasp the fundamental principles of artificial intelligence and machine learning.
- Learn key terminology and concepts used in AI and ML.
- Apply AI and ML techniques to solve problems in the field of physics.
- Differentiate between and apply supervised and unsupervised learning techniques.
- Implement regression, classification, and prediction models.
- Use popular ML libraries and tools such as TensorFlow, PyTorch, and scikit-learn.
- Implement AI and ML techniques in practical, hands-on projects and case studies.
- Use advanced digital tools autonomously for one or more professions or research sectors in the field.
- Conduct a reflective and distanced analysis, considering the issues, challenges, and complexity of a request or situation, to propose appropriate and/or innovative solutions in compliance with regulatory developments.
- Develop predictive tools based on validated models describing complex physical problems.
- Program digital tools to process physical measurements in a relevant manner (potentially using machine learning and AI approaches).

Modalités d'évaluation
Evaluation : isolée *Continuous assessment and project* *The course evaluation will consist of two main parts:* ■ *Multiple Choice Quiz at the beginning of some lectures (30%)* ■ *Project leading to a written report of analysis and interpretation of a dataset (70%)*

ATOMIC SCALE MODELING I – CLASSICAL METHODS

UE : ATOMIC SCALE MODELING I – CLASSICAL METHODS

BCC1: IMPLEMENTING FUNDAMENTAL PHYSICS TOOLS AND APPROACHES TO PRODUCE HIGHLY SPECIALIZED KNOWLEDGE

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Céline Toubin*
List of potential teachers: Frederic Affouard, Charlotte Bequart, Philippe Carrez, Céline Toubin

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**12**		**16**		**28**

Required prior teaching unit(s):

Suggested readings:

-

Syllabus :

Discover powerful simulation techniques like Molecular Dynamics and Monte Carlo to predict and design material properties at the atomic scale.

Objectives :

1. Identify when and why to use atomistic simulations in research and development.
2. Apply optimization techniques to obtain stable atomic or molecular structures.
3. Set up and adapt force-field models for different material systems.
4. Get the principles of Monte Carlo methods for configurational sampling.
5. Analyze simulation outputs using relevant physical and statistical quantities.

Course outline

- Why performing simulations?
- Optimization Techniques
- Force-field description
- Molecular dynamics principles: forces evaluation and cut off, periodic boundary conditions, minimum image convention, thermostat, barostat, statistical averages and observables
- Montecarlo
- Hands on practicals

Skills acquired

- **Optimize atomic structures** using energy minimization and relaxation techniques.
- **Identify appropriate simulation methods** (MD or MC) for solving material and molecular-scale

problems.

- **Understand and evaluate force-field models** for specific systems to achieve reliable predictive accuracy.
- **Implement key MD concepts**, including thermostats, barostats, cutoffs, and periodic boundary conditions.
- **Apply statistical mechanics principles** to extract thermodynamic and structural observables from simulation data.

Modalités d'évaluation
Evaluation : isolée Report (XX%) and oral presentation (XX%)

STATES OF MATTER AND MATERIALS SCIENCE PRIMERS

UE : STATES OF MATTER AND MATERIALS SCIENCE PRIMERS
BCC1: IMPLEMENTING FUNDAMENTAL PHYSICS TOOLS AND APPROACHES TO PRODUCE HIGHLY SPECIALIZED KNOWLEDGE

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Valérie Gaucher valerie.gaucher@univ-lille.fr*
List of potential teachers: Tiana Deplancke, Sophie Barrau, Franck Beclin, Mathieu Touzin

Teaching volume	**CM**	**C-TD**	**TD**	**TP**	**Remote**	**Total**
Supervised teaching hours		**24**				**24**

Required prior teaching unit(s):

Suggested readings:

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Syllabus :

Have a clear understanding of the different families of materials (metals and alloys, ceramics, polymers) based on their properties and microstructure.

Objectives :
This course aims to present the different classes of materials based on their chemical bonds. The microstructure and the specific properties Three major classes of materials will be detailed: ceramics, metal and alloys and polymers.

Outline:
1. Generalities : the state of matter, crystalline and amorphous materials, Phenomenological approach of the diffusion process in gas and solid.
2. Introduction to material science : Chemical bounding and the resulting physical and mechanical properties. Ashby diagram and main classes of materials.
3. Ceramics : Introduction, properties and applications, diffusion process and elaboration process (sintering ...)
4. Metals and alloys : Definition and structure, Phase diagram, phase transformation and microstructure resulting. Study case : Steel and iron carbon diagram.
5. Polymers : Definition, macromolecular conformation, viscosity, classification of polymers, phenomenological and thermodynamical approaches of the glass transition, nucleation and growth of crystals, melting behavior.

Skills acquired:
By the end of this course, students will have a clear understanding of the different families of materials

(metals and alloys, polymers, ceramics). They will know the main characteristics (structure, end use properties).

Modalités d'évaluation
Evaluation : isolée CC (1/2) CT (1/2)

FOREIGN LANGUAGE : ENGLISH OR FRENCH

UE : FOREIGN LANGUAGE

BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT

Choice-based classes
Teaching method: as required, remote or in person
Teaching language: as required

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours						

Required prior teaching unit(s):

Suggested readings:

-

Syllabus :

Improve your communication skills in a foreign language

Modalités d'évaluation

CC, CT, rapport, soutenance orale,... + pondérations

PE OR GRADUATE PROGRAM SPECIAL TEACHING

UE : PE OR GP

BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT

Choice-based classes
Teaching method: as required, remote or in person
Teaching language: as required

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours						

Required prior teaching unit(s):

Suggested readings:

-

Syllabus :

Learn on current topic from the Materials for a Sustainable Future graduate program

Modalités d'évaluation

CC, CT, rapport, soutenance orale,... + pondérations

TUTORED TRAININGS

UE : TUTORED TRAININGS

BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Sébastien Merkel* – sebastien.merkel@univ-lille.fr

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**4.5**	**6**			**10.5**

Required prior teaching unit(s):

Suggested readings:

6.

Syllabus :

Discovery of new topics in physics based on the scientific literature and develop your teaching and presentation skills in front of your peers.

Objectives
Promote scientific openness among Physics Masters students. Complement their training in subjects not covered in traditional courses. Develop students' ability to work independently using information from the literature. Develop professional skills (oral presentation, scientific writing, and poster presentation

Course outline
Students choose 1 work topic in pairs. Topics are proposed by department staff, based on scientific articles, books, etc and can cover any field of physics.
The teaching consists in 6 in-person session guided by a main instructor, assistance from tutors, and significant personal work from the students based on information found in the University library and the scientific literature.
In person activities:

- Class 1 (1h30 CTD) Introduction, choice of subject, expectations
- Class 2 (1h30 TD, 3 groups QPT, PMM, BIOPHAM): Mid-course presentation, 10 minutes per pair, plan
- Class 3 (1h30 TD, 3 groups) Presentation analysis session (based on students reports on the presentations of others, and on their own)
- Class 4 (1h30 CTD) Latex and overleaf
- Class 5 (1h30 CTD) Report preparation
- Class 6 (1h30 TD, 3 groups) Final oral

Tutor activities

- propose a lead for topic (title, keywords, and references)
- 3 individual meetings with the student pair they supervise
- First contacts, first publications
- Assessment of students' individual research and understanding of the topic
- Detailed plan of report
- Proofreading and evaluation of reports
- Participation in evaluation of oral defenses

Acquired skills
Develop advanced and critical expertise at the edge of knowledge in a sub-field of physics based on documents from the recent scientific literature
Identify, select, and critically analyze specialized resources to document a topic and make a synthesis and exploit their content
Present advanced scientific content in front of your peers

Modalités d'évaluation

Evaluation : isolée
Report (1/3)
Oral defense (1/3)
Response to questions (1/3)

CONTINUUM MECHANICS

UE : CONTINUUM MECHANICS

BCC3: SOLVING COMPLEX PROBLEMS BY APPLYING FUNDAMENTAL PHYSICS CONCEPTS

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Philippe Carrez* – philippe.carrez@univ-lille.fr
List of potential teachers: Philippe, Sebastien, Frederic, Valerie, Franck, Mathieu, Patrick

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**24**				**24**

Required prior teaching unit(s):

Suggested readings:

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Syllabus :

Continuum mechanics is a fundamental theory of many fields of science and engineering. This course will give an introduction to the principles of stress, strain, anisotropic and isotropic elasticity with applications covering a broad area relating to the mechanical behavior of materials.

Requires

- Basis of linear algebra and crystallography

Objectives :

- acquire the basic concepts of continuum mechanics
- Define and manipulate stress and strain tensor, apply tensor transformation
- Analytically solve simple problems of elasticity

Course outline

- Stress and strain as a second-rank tensor
- Fondamental equations of elasticity, Hooke's law
- Navier equations
- Review of macroscopic plastic behavior of matter
- Principles stresses and yield criterion

Skills acquired

Students will be able to manipulate fundamental equations of elasticity theory and acquire knowledge of several techniques of resolution of different problems at different length scales.

Modalités d'évaluation

Evaluation : isolée
CC, CT, rapport, soutenance orale,... + pondérations

STATISTICAL PHYSICS AND CRITICAL PHENOMENA

UE : STATISTICAL PHYSICS AND CRITICAL PHENOMENA

BCC3: SOLVING COMPLEX PROBLEMS BY APPLYING FUNDAMENTAL PHYSICS CONCEPTS

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Adam Rançon* – adam.rancon@univ-lille.fr
List of potential teachers: Laurent Carpentier, Adam Rançon, Radu Chicireanu, Abdelkader, Frederic, Alexandre Feller

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**24**				**24**

Required prior teaching unit(s):

Suggested readings:

1.

Syllabus :

This course introduces fundamental concepts in statistical physics, focusing on Bose-Einstein and Fermi-Dirac statistics, phase transitions, critical phenomena, and the renormalization group. It covers key models like the Ising model and Landau theory, providing tools for analyzing quantum gases and critical phenomena.

Prerequisites
Probabilistic description, ensembles (micro, cano, grand cano) ; Partition function, thermodynamic potentials.

Objectives
Ce cours vise à fournir aux étudiants une compréhension des concepts fondamentaux en physique statistique, en abordant les statistiques de Bose-Einstein et de Fermi-Dirac, ainsi que les propriétés des gaz quantiques. Il couvre les transitions de phase, en introduisant la limite thermodynamique, les phénomènes critiques, et les modèles classiques tels que le modèle d'Ising et la théorie de Landau. L'enseignement inclura également une introduction à la théorie du champ moyen et au groupe de renormalisation, des outils essentiels pour analyser les transitions de phase et les phénomènes universels dans les systèmes physiques complexes.

Course outline
Statistiques BE et FD ; Bose and Fermi gases ;
What are a phase transition ? Order paramter, spontanueous symmetry breaking and thermodynamic limit
Critical phenomena, Landau theory, mean field, with application to the Ising model
Introduction to statistical field theory, correlation functions and gaussian fluctuations
Introduction to the renormalisation group : breakdown of mean-field theory, Ising 1D and decimation, Kadanoff block-spins
Notes : Regarder ce qui sera fait en L3 - nouvelle maquette ! Coordonner avec Cond Mat – electrons (S1 commun)

et Phys Stat hors-equilibre (QPT, S2)

Acquired skills
À l'issue de ce cours, les étudiants auront acquis la capacité d'appliquer les statistiques de Bose-Einstein et de Fermi-Dirac, de caractériser les transitions de phase et les phénomènes critiques, ainsi que d'utiliser la théorie du champ moyen et le groupe de renormalisation pour analyser les gaz quantiques et les systèmes critiques. Ils sauront également interpréter les propriétés thermodynamiques des gaz de Bose et de Fermi en lien avec les transitions de phase.

Modalités d'évaluation

Evaluation : isolée
CC, CT, rapport, soutenance orale,... + pondérations

CONDENSED MATTER I – ELECTRONS

UE : CONDENSED MATTER I – ELECTRONS

BCC3: SOLVING COMPLEX PROBLEMS BY APPLYING FUNDAMENTAL PHYSICS CONCEPTS

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Gaëtan Lévêque* – gaetan.leveque@univ-lille.fr
List of potential teachers: Laurent, Gaëtan, Alexandre Feller, Yan, Matthieu Touzin, Philippe

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**24**				**24**

Required prior teaching unit(s):

Suggested readings:
1.

Syllabus :

Basics on electronic properties in solid state physics, covering equilibrium and transport properties of crystalline solids, from the Sommerfeld model to semi-conductors.

Prerequisites
Basics on crystallography and Bravais lattices, quantum mechanics and statistical physics at bachelor level.

Objectives
Students will learn how to connect microscopic properties of electrons in solids from quantum mechanics and macroscopic properties (internal energy, heat capacity, electrical and thermal conductivity) from statistical physics. Starting from the simplest model of free electrons, we will expand it to crystalline solids to cover band theory, finally making the distinction between metals, insulators and semi-conductors.

Course outline
- Context, Born-Oppenheimer and single-electron approximation (3/4h)
- Sommerfeld model (density of states, Fermi sphere, chemical potential, internal energy, heat capacity) (3 1/4h)
- Band theory : nearly-free electrons, metal/insulators/semi-conductors, tight-binding model if time. (3,5h)
- Semi-conductors : electrons and holes description, intrinsic/extrinsic SC, homogeneous/heterogeneous SC, PN junction (3,5 h)

Skills acquired

Modalités d'évaluation

Evaluation : isolée
Final exam

ATOMIC PHYSICS

UE : ATOMIC PHYSICS

BCC3: SOLVING COMPLEX PROBLEMS BY APPLYING FUNDAMENTAL PHYSICS CONCEPTS

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Céline Toubin* – celine.toubin@univ-lille.fr
List of potential teachers: Céline Toubin, Thèrèse Huet, Hervé Herbin, Claire Pirim

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**24**				**24**

Required prior teaching unit(s):

Suggested readings:
- Mécanique quantique, C. Cohen-Tannoudji, B. Diu, F. Laloë (Hermann).
- Molecular quantum mechanics / Atkins
- Physics of atoms and molecules / Bransden
- Atoms and molecules interacting with light / Van der Straten

Syllabus :

This course provides an introduction to atomic physics. You will explore the quantum mechanical description of both single and multi-electron atoms. By studying the fundamental properties of atoms, you will gain a deeper understanding of the periodic table's structure. Furthermore, you will investigate how atoms interact with light and how their spectra provide insights into these systems.

Prerequisites:
Basics of quantum physics (L3); hydrogen atom; quantization of angular momentum; harmonic oscillator; Special relativity; electromagnetism ; Hamiltonian mechanics

Objectives:
This advanced course delves into the intricate interactions between light and matter at atomic scales. We will explore fundamental concepts based on quantum physics to describe the structure of atoms containing several electrons and the spectral signatures resulting from their interactions with electromagnetic fields.

Course outline
- Atom with 1 electron : Interaction with an external electric or magnetic field,
  - Fine structure
  - The Zeeman effect,
  - The Stark effect
  - Hyperfine structure

- Atom with two electrons :
    - The Schrödinger equation of 2-electron atoms, ortho and para states
    - Spin wave functions and the Pauli exclusion principle
    - The independent particle model
    - The ground state of the 2-electron atoms
    - Excited states of the 2-electron atoms
- Atom with many electron
    - (Slater determinants), variational method, Hartree-Fock
    - The central field approximation
    - The periodic classification of the elements
    - The Hartree-Fock method
    - Corrections to the central field approximation
- The interaction of many-electron atoms with electromagnetic fields
- Selection rules (if times allows, otherwise fairly Light-matter interaction)

Skills acquired
- Apply fundamental quantum mechanical concepts and methods to problems in atomic physics.
- Analyze basic atomic spectra.
- Solve complex theoretical and numerical problems using advanced quantum and mathematical methods.
- Relate examples to current research in atomic physics.
- Evaluate the applicability and limitations of physical models relevant to atomic physics.

Modalités d'évaluation

Evaluation : isolée
Final exam

CLASSES IN SEMESTER S2

List of acronyms:

- BCC: Bloc de Compétence et Compétence = teaching block
- UE: Unité d'Enseignement = teaching unit
- CM: Cours magistral = main class
- TD: Travaux Dirigés = practicals
- C-TD: Cours-TD = mix of classes and practicals
- TP: Travaux Pratiques = labs

SATELLITES AND REMOTE SENSING

UE : SATELLITES AND REMOTE SENSING

BCC1: IMPLEMENTING FUNDAMENTAL PHYSICS TOOLS AND APPROACHES TO PRODUCE HIGHLY SPECIALIZED KNOWLEDGE

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Quentin Coopman* – quentin.coopman@univ-lille.fr
List of potential teachers: Céline Cornet celine.cornet@univ-lille.fr, Philippe Goloub philippe.goloub@univ-lille.fr, Jérôme Riedi jerome.riedi@univ-lille.fr, Quentin Coopman quentin.coopman@univ-lille.fr

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		14		12		26

Required prior teaching unit(s):

Suggested readings:
2.

Syllabus :

Master the principles and applications of remote sensing and satellite technology through comprehensive lectures and practical work with insights into environmental monitoring and cutting edge research.

Objectives
This course aims to provide students with a comprehensive understanding of remote sensing and satellite technology. Students will learn to analyze, interpret, and evaluate data using passive and active sensing techniques, gain hands-on experience with advanced measurement instruments, and estimate these methods to real-world challenges. The course also focuses on developing critical thinking and presentation skills through the explication and evaluation of cutting-edge research.

Course outline
- General Introduction (2H)
  - Importance of remote sensing and historical overview
  - Basics of Orbitography, types (LEO, GEO, ...) and their applications
- Measurement vectors (5H)
  - Platforms for remote sensing: ground-based, satellite-based, balloon, airplane, etc.
  - Observation systems (imagers, spectroradiometers, etc.)
  - Resolution and distorsion: spatial, spectral, radiometric, types of distortion, and correction methods
- Passive solar and thermal remote sensing (4H)

- Exploitation of multispectral information and polarisation (applications and advantages)
- Stereoscopy (principle, techniques, applications);
- Passive remote sensing (application for clouds, vegetation, fires, etc.)

- Lidar and Radar active remote sensing (4H)
  - Introduction to Lidar and Radar
  - Basic principles and introduction to radar interferometry (Synthetic Aperture Radar –SAR – and Interferometric SAR – InSAR)
  - Applications (e.g. Lidar for topographic mapping, tree detection, atmospheric studies ; weather radar for meteorological applications; Sentinel1 missions and applications)

Practical work (12H):

- Measurements with CHRIS (3 hours): Hands-on experience with the Compact High Resolution Imaging Spectroradiometer.
- Photometry (3 hours): Practical exercises in measuring light properties and spectral characteristics.
- Lidar (3 hours): Data analysis using the Lidar instrument.
- AERIS Data and Products (3 hours): Working with data from space-based instruments such as IASI and 3MI.

Bibliographic review of a research article to be read and presented on a remote sensing technique/application

Acquired skills

- Mobilise highly specialised knowledge, some of which is at the forefront of knowledge in remote sensing techniques
- Analysis of physical phenomena using successive approximations
- Interpret the results of measurements and observations made during physical experiments and provide estimates of their uncertainties
- Identify, select and analyse critically bibliographic resources related to remote sensing technique and applications.
- Communicate orally for knowledge transfer purposes.

Modalités d'évaluation

Evaluation : isolée
50 % written exam
30 % practical works evaluation
20 % oral presentation of a bibliographic review

RADIATIVE TRANSFER AND RADIATION-MATTER INTERACTIONS

UE : RADIATIVE TRANSFER AND RADIATION-MATTER INTERACTIONS

BCC1: IMPLEMENTING FUNDAMENTAL PHYSICS TOOLS AND APPROACHES TO PRODUCE HIGHLY SPECIALIZED KNOWLEDGE

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Hervé Herbin* – herve.herbin@univ-lille.fr
List of potential teachers: Hervé Herbin, Nicolas Ferlay, Fabien Waquet

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**17**		**9**		**26**

Required prior teaching unit(s):

Suggested readings:

-

Syllabus :
Master the principles and applications of radiation-matter interaction in the context of atmospheric studies. Through a good balance between theoretical, numerical and practical elements. Objectives This course aims to provide students with a thorough understanding of the theoretical and practical elements related to the use of light-matter interaction as an analytical and diagnostic tool in dilute environments, particularly the atmosphere. Although the concepts presented are generalizable to other scientific fields, this course will be placed in the context of current societal issues such as climate, meteorology, and air quality. Course outline 1. Principles in atmospheric radiation (4H) a. Atmospheric structure and radiative budget b. Grey-body radiation, solar spectrum and surface properties 2. Radiative transfer in absorbing medium (4H) a. Calculation of radiation-matter interaction for high frequency phenomena b. Calculation of radiation-matter interaction for low frequency phenomena c. Introduction to codes and databases d. Applications to GES and trace gases 3. Radiative transfer in scattering medium (4H) • Radiation scattering by spherical and non-spherical particles

- Particles optical properties and spectroscopy of condensed phase
- Polarized radiation
- Introduction to codes and databases
- Applications to aerosols and clouds

4. Inverse problems in radiative transfer (4H)
   a. Theoretical basis
   b. Basic principles for atmospheric studies
   c. Applications to gas, aerosols and clouds

Practical work (9H):

- Resolution of radiative transfer equation from Arahmis algorithm (3 hours): Quantitative simulation of light-matter interaction in absorbing medium.
- Resolution of radiative transfer equation in scattering medium (3 hours): Practical exercises to quantify different chemical and µ-physical effect on scattering.
- Simulation of cloudy observation from SBDART algorithm (3 hours): Quantitative simulation of atmospheric clouds and impact

Acquired skills

- Acquire a solid basis (mathematics and physics) in the context of radiative transfer.
- Be able to understand and analyze optical phenomena and make connections with physico-chemical information.
- Simulate, predict, and interpret light-matter interactions in dilute media.
- Use this knowledge by being able to apply it to atmospheric studies.

Modalités d'évaluation
Evaluation : isolée 70 % written exam 30 % practical works evaluation

LARGE SCALE RESEARCH INFRASTRUCTURES

UE : LARGE SCALE RESEARCH INFRASTRUCTURES

BCC1: IMPLEMENTING FUNDAMENTAL PHYSICS TOOLS AND APPROACHES TO PRODUCE HIGHLY SPECIALIZED KNOWLEDGE

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Manuel Goubet* – manuel.goubet@univ-lille.fr
List of potential teachers: Eleonore Roussel eleonore.roussel@univ-lille.fr, Jean-François Brun jfbrun@univ-lille.fr, Suzanne Crumeyrolle suzanne.crumeyrolle@univ-lille.fr, Andre Gomes andre.gomes@univ-lille.fr, Laurent Margulès laurent.margules@univ-lille.fr

Teaching volume	**CM**	**C-TD**	**TD**	**TP**	**Remote**	**Total**
Supervised teaching hours		**20**	**4**	**3**		**27**

Required prior teaching unit(s):

Suggested readings:

-

Syllabus :

Objectives
This course aims to introduce students to the principles, functioning, and applications of major large scale research infrastructures (LSRI) used in both fundamental and applied research. It also seeks to develop cross-disciplinary skills such as literature review, critical analysis, and scientific communication.

Course outline
1. General Introduction (2h)
   Importance of LSRI, historical perspective, functioning, and scientific challenges
2. Examples of scientific advancements thanks to LSRI (4.5h)
   The Higg's boson
   Gravitational waves
   Event horizon of M87 black hole
3. Case Study 1: Synchrotron Radiation (4.5h)
   Working principles and applications
   Introduction to coherent light sources (CLS)
4. Case Study 2: Neutron Sources (2h)
   Working principles and applications
   Examples of performed researches
5. Case Study 3: ACTRIS: Aerosol, Clouds and Trace Gases Research Infrastructure (3h)

Working principles and applications
Examples of performed researches

6. Case Study 4: Millimeter/Submillimeter Astrophysics (3h)
   Principles and significance of radio telescopes
   Overview of major observatories: ALMA, GBT and NOEMA
   Role in detecting prebiotic species and understanding the origins of life
7. Case Study 5: Large Intensive Computing Equipment (2h)
   Working principles, applications in physics, chemistry, and biology
   Overview of major French facilities: CINES, IDRIS and TGCC
   Examples of performed researches
8. Visit of a research infrastructure (3h)
9. Bibliographic review of a research article based on LSRI (4h)

Acquired skills

- Understanding the physical concepts underlying modern scientific instrumentation
- Knowledge of how large scale research infrastructures operate
- Ability to identify and analyze fundamental physical phenomena
- Ability to analyze and interpret scientific literature
- Clear and concise written and oral scientific communication

Modalités d'évaluation
Evaluation : isolée 40 % written exam 40 % oral presentation of bibliographic review 20 % written report of laboratory visit

EXPERIMENTAL PROJECT

UE : EXPERIMENTAL PROJECT

BCC1: IMPLEMENTING FUNDAMENTAL PHYSICS TOOLS AND APPROACHES TO PRODUCE HIGHLY SPECIALIZED KNOWLEDGE

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Manuel Goubet* – manuel.goubet@univ-lille.fr
List of potential teachers: Suzanne Crumeyrolle suzanne.crumeyrolle@univ-lille.fr, François Anquez francois.anquez@univ-lille.fr, Clément Evain clement.evain@univ-lille.fr

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours				**24**		**24**

Required prior teaching unit(s):

Suggested readings:

-

Syllabus :

Objectives
This course aims to develop students' autonomy, scientific rigor, and technical skills through the realization of an experimental project in pairs. It involves applying theoretical knowledge acquired so far to solve a real-world problem.

Course outline
- Design and implementation of an experimental setup or technical study
- Development of measurement protocols
- Use of specialized software
- Use of instruments related to the project
- Critical analysis of results
- Writing of a scientific report and oral presentation of the work

Acquired skills
- Project management in a team setting
- Development of an experimental scientific approach
- Proficiency in digital and instrumental tools
- Critical analysis of experimental data
- Autonomy and initiative
- Bibliographic research and data synthesis
- Professional communication (written and oral)
- Teamwork and collaboration

Modalités d'évaluation

Evaluation : isolée
33% CC (logbook, implication)
33% written report
33% oral presentation

TUTORED TRAININGS

UE : TUTORED TRAININGS

BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Sébastien Merkel* – sebastien.merkel@univ-lille.fr

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours						

Required prior teaching unit(s):

Suggested readings:

-

Syllabus :

Discovery of new topics in physics based on the scientific literature and develop your teaching and presentation skills in front of your peers.

Objectives
Promote scientific openness among Physics Masters students. Complement their training in subjects not covered in traditional courses. Develop students' ability to work independently using information from the literature. Develop professional skills (oral presentation, scientific writing, and poster presentation

Course outline
Students choose 1 work topic in pairs. Topics are proposed by department staff, based on scientific articles, books, etc and can cover any field of physics.
The teaching consists in 6 in-person session guided by a main instructor, assistance from tutors, and significant personal work from the students based on information found in the University library and the scientific literature.
In person activities:

1. Class 1 (1h30 CTD) Introduction, choice of subject, expectations
2. Class 2 (1h30 TD, 1 group): 3 minutes pitch on the topic of study
3. Class 3 (1h30 TD, 1 group): Presentation analysis session (based on students reports on the presentations of others, and on their own)
4. Class 4 (1h30 CTD) Report preparation
5. Class 5 (1h30 CTD) Poster preparation
6. Class 6 (3h00 TD) Poster session

Tutor activities

- propose a lead for topic (title, keywords, and references)
- 3 individual meetings with the student pair they supervise
- First contacts, first publications
- Assessment of students' individual research and understanding of the topic
- Detailed plan of report
- Proofreading and evaluation of reports
- Participation in the poster session

Acquired skills
Develop advanced and critical expertise at the edge of knowledge in a sub-field of physics based on documents from the recent scientific literature
Identify, select, and critically analyze specialized resources to document a topic and make a synthesis and exploit their content
Present advanced scientific content in front of your peers

Modalités d'évaluation

Evaluation : isolée
Report (1/3)
Poster (1/3)
Response to questions (1/3)

INTERNSHIP

UE : INTERNSHIP

BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Sébastien Merkel* – sebastien.merkel@univ-lille.fr

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours						

Required prior teaching unit(s):

Suggested readings:

-

Syllabus :

A two-month-long experience in a professional working environment

Modalités d'évaluation

Evaluation : isolée
CC, CT, rapport, soutenance orale,... + pondérations

CONDENSED MATTER II – PHONONS

UE : CONDENSED MATTER II – PHONONS

BCC3: SOLVING COMPLEX PROBLEMS BY APPLYING FUNDAMENTAL PHYSICS CONCEPTS

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Yan Pennec* – yan.pennec@univ-lille.fr
List of potential teachers: Yan, Frederic, Gaetan, Laurent

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**24**				**24**

Required prior teaching unit(s):

Suggested readings:

-

Syllabus :

This lecture explores the vibrational properties of crystalline solids, from lattice symmetries and phonon dispersion to thermodynamic behavior. It provides the fundamental tools to understand heat capacity, thermal transport, and the quantum nature of lattice vibrations in condensed matter systems.

Prerequisites
Condensed Matter I (S1), Statistical Physics (L3), Crystallography. Bravais Lattices / Reciprocal Lattices / Brillouin Zone / Sum Rule, Fourier Analysis

Objectives
This course provides a rigorous introduction to the vibrational properties of crystalline solids. It develops the theoretical framework for lattice dynamics using classical and quantum models. It explains phonon dispersion, density of states, and their influence on thermodynamic properties. It analyzes how phonons govern specific heat, thermal conductivity, and electron interactions. It lays the foundation for understanding thermal and vibrational phenomena in condensed matter physics.

Course outline
Chapter 2: Dynamics of the Crystal Lattice :
Introduction / Harmonic Approximation / Vibrations of a One-Dimensional Atomic Lattice / Extension to Two and Three Dimensions / Quantification of Vibrations: Phonons / Conclusion
Chapter 3: Crystal Lattice Dynamics II
Introduction / Density of States / Thermodynamic Properties / Einstein Model of Specific Heat / Debye Model of Specific Heat / Phonon Scattering and Thermal Conductivity
Chapter 4 : Phonon Transport / Anharmonic Effects / Thermal dilatation (Grüneisen coefficient).

Acquired skills
At the end of the course, students are able to acquire and analyze phonon dispersion relations derived from lattice dynamics in one, two, and three dimensions. They can interpret how phonons influence the thermal and electronic properties of solids, including specific heat and thermal conductivity. They understand and apply the Debye and Einstein models to explain the temperature dependence of specific heat, and can evaluate the role of electron-phonon interactions in condensed matter systems. They are also proficient in using theoretical frameworks—such as the harmonic approximation and the Brillouin zone formalism—to model and interpret the vibrational behavior of crystalline solids.

Modalités d'évaluation

Evaluation : isolée
CC, CT, rapport, soutenance orale,... + pondérations

FUNDAMENTALS OF MOLECULAR SPECTROSCOPY

UE : FUNDAMENTALS OF MOLECULAR SPECTROSCOPY

BCC3: SOLVING COMPLEX PROBLEMS BY APPLYING FUNDAMENTAL PHYSICS CONCEPTS

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Roman Motiyenko* – roman.motiyenko@univ-lille.fr

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**24**				**24**

Required prior teaching unit(s): Quantum mechanics, Atomic Physics

Suggested readings:
- C. Banwell, *Fundamentals of Molecular Spectroscopy*
- P.R. Bunker, P. Jensen *Fundamentals of Molecular Symmetry*
- P. Bernath*, Spectra of Atoms and Molecules*

Syllabus :

Course Objectives : Students will gain a solid understanding of the quantum mechanical principles behind molecular spectroscopy, with emphasis on rotational and vibrational transitions and the role of symmetry in determining spectroscopic activity.

- Block 1: Foundations & Born-Oppenheimer Approximation
  - Session 1: Introduction to molecular spectroscopy
    - Spectroscopic domains (microwave, IR, Raman)
    - Energy level structure of molecules
    - Overview of the molecular Hamiltonian
  - Session 2: Born-Oppenheimer approximation
    - Separation of electronic, vibrational, and rotational motion
    - Potential energy surfaces and electronic states

- Block 2: Molecular Rotation
  - Session 3: Rigid rotor model – Diatomics
    - Quantum mechanics of rotation
    - Rotational energy levels
  - Session 4: Rotational spectra of linear and symmetric top molecules
    - Selection rules (qualitative)
    - Effects of molecular structure on spectra
  - Session 5: Non-rigid rotor and centrifugal distortion
    - Real molecule corrections
    - Examples and simple spectra

- Block 3: Molecular Vibration
    - Session 6: Harmonic oscillator and vibrational quantization
        - Vibrational energy levels
        - IR activity of diatomics
    - Session 7: Normal modes in polyatomic molecules
        - Cartesian vs internal coordinates
        - Normal mode classification
    - Session 8: Anharmonicity and rovibrational transitions
        - Overtones, hot bands
        - Introduction to vibration-rotation spectra

- Block 4: Molecular Symmetry & Group Theory
    - Session 9: Symmetry elements and operations
        - Point groups, molecular examples
    - Session 10: Representations and character tables
        - Reducible and irreducible representations
        - Application to molecular motions
    - Session 11: Vibrational mode classification using group theory
        - Normal mode symmetry
        - Prediction of IR and Raman activity

- Block 5: Spectral Intensities & Selection Rules
    - Session 12: Transition dipole moments and intensity
        - Time-dependent perturbation theory overview
        - Einstein coefficients
    - Session 13: Symmetry-based selection rules
        - Direct product and integral criterion
        - Rotational and vibrational transition probabilities

- Block 6: Applications & Interpretation
    - Session 14: Interpretation of rotational spectra
        - Case studies (e.g., HCl, CO)
        - Spectroscopic constants and molecular geometry
    - Session 15: Interpretation of vibrational spectra
        - IR and Raman of polyatomic molecules
        - Examples: CO_2, H_2O, NH_3, etc.
    - Session 16: Final review and problem-solving workshop
        - Mixed exercises and discussion
        - Clarification of key concepts

Modalités d'évaluation

Evaluation : isolée
CT : 100%

MICROSTRUCTURES AND DEFECTS IN MATERIALS

UE : MICROSTRUCTURES AND DEFECTS IN MATERIALS

BCC3: SOLVING COMPLEX PROBLEMS BY APPLYING FUNDAMENTAL PHYSICS CONCEPTS

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Sébastien Merkel* – sebastien.merkel@univ-lille.fr
List of potential teachers: F. Béclin, A. Néri, Ph. Carrez

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**24**				**24**

Required prior teaching unit(s):

Suggested readings:

-

Syllabus :

Materials are made of grains, defects, and other microstructural elements. The arrangement microstructural elements control the physical properties of materials and are the object of intense research and analysis, both in academic research, to understand the fundamentals of materials's plasticity or the history of deformation in the Earth's mantle, but also in direct contact with day-to-day applications, from the making of a beer canister to the effect of radiations inside a nuclear reactor.

Objectives
This class will help students understand:
- how microstructures control material performance and properties,
- the methods used to characterize and model microstructural development,
- the underlying physical principles governing microstructural evolution in a material,
- the prediction of materials properties based on modeling and EBSD observations.

The class will include classical teaching as well as hands on experience with data and computer software.

Course outline
Part I : Microscopic scale (8 hours)
- Elements of materials microstructures: phases, grains, defects, grain boundaries
- Dislocations and defects
- Crystal growth

Part II : Polycrystal scale (8 hours)
- Representation of microstructures: Euler angles, orientation distribution function, pole figures and inverse

pole figures,

- Observation in electron microscopy and EBSD
- Plastic deformation: Schmid factor, Taylor and Sachs bounds, numerical modeling methods
- Polycrystal mechanical properties

Part III : Hands on experience (8 hours)

- Microstructure visualization with MTeX
- Visco-plastic self consistent modeling
- Interpretation of EBSD observations

Skills acquired

Modalités d'évaluation

Evaluation : isolée
Table exam on part I. Table exam on part II. Report of data interpretation and microstructure modeling.

CLASSES IN SEMESTER S3

List of acronyms:

- BCC: Bloc de Compétence et Compétence = teaching block
- UE: Unité d'Enseignement = teaching unit
- CM: Cours magistral = main class
- TD: Travaux Dirigés = practicals
- C-TD: Cours-TD = mix of classes and practicals
- TP: Travaux Pratiques = labs

STRUCTURAL PROPERTIES OF MATTER : ELECTRON MICROSCOPY AND DIFFRACTION

UE : STRUCTURAL PROPERTIES OF MATTER : ELECTRON MICROSCOPY AND DIFFRACTION

BCC1: IMPLEMENTING FUNDAMENTAL PHYSICS TOOLS AND APPROACHES TO PRODUCE HIGHLY SPECIALIZED KNOWLEDGE

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Sébastien Merkel* – sebastien.merkel@univ-lille.fr
List of potential teachers: S. Merkel, D. Jacob

Teaching volume	**CM**	**C-TD**	**TD**	**TP**	**Remote**	**Total**
Supervised teaching hours		**16**	**9**	**6**		**31**

Required prior teaching unit(s):

Suggested readings:

-

Syllabus :

Characterize the state of materials at the crystal to nanometer scale using advanced experimental methods such as the scanning and transmission electron microscope, and powder X-ray diffraction

Objectives
This course introduces advanced techniques for structural characterization of materials, with a focus on electron microscopy and X-ray diffraction. The student will learn the fundamentals of light-matter interactions, materials characterization with scanning and transmission electron microscope, and powder X-ray diffraction. The course includes hands-on practicals on the SEM and TEM and data processing of powder X-ray diffraction using the Rietveld method.

Course outline
In class courses

1. 6 h-CM:
    2. Introduction to material’s characterization methods,
    3. Light-matter interaction,
    4. Powder X-ray diffraction and Rietveld implementation
5. 10 h-CM: Electron microscopy
    6. Electron-matter interactions

7. Basics of Scanning Electron Microscopy: signals, imaging, chemical analysis
8. Basics of Transmission Electron Microscopy: optics, imaging, diffraction, chemical analysis and spectroscopy

In class practicals

- 6 h-TD : Powder X-ray diffraction data processing using the Rietveld method
- 3 h-TD : TEM data analysis

Labs, as small groups

- 3h SEM, 4 groups
- 3h TEM, 4 groups

Acquired skills

- Analysis and interpretation of powder X-ray diffraction data using the Rietveld method
- Study of materials properties using the SEM and TEM
- Identification, use, and interpretation of advanced experimental methods for the characterization of materials
- Develop and conduct complex experiments using advanced technological equipments

Modalités d'évaluation

Evaluation : isolée

Report on Rietveld analysis (1/3)
Report on Electron microscopy (1/3)
Final exam (1/3)

ATOMIC SCALE MODELING II

UE : ATOMIC SCALE MODELING II

BCC1: IMPLEMENTING FUNDAMENTAL PHYSICS TOOLS AND APPROACHES TO PRODUCE HIGHLY SPECIALIZED KNOWLEDGE

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Denis Duflot* – Denis.Duflot@univ-lille.fr
List of potential teachers: Denis Duflot, Philippe Carrez, Pierre Hirel

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**16**		**12**		**28**

Required prior teaching unit(s):

Suggested readings:

-

Syllabus :
Discover quantum first principles methods to solve the problem of the electronic structure of molecular systems, from isolated molecules to solids Objectives 1. Identify when and why to use quantum methods for research problems 2. Find stable equilibrium structures. 3. Calculate relevant physical and/or chemical properties Course outline • The electronic structure problems for molecular systems: how to solve the Schrödinger equation? • The Hartree-Fock approximation • Linear Combination of Atomic Orbitals and basis sets, pseudo-potentials • Semi-empirical methods; from Hückel to DFTB • Beyond Hartree-Fock : the correlation problem • Basics of post-Hartree Fock methods • Density Functional Theory (DFT): basic concepts and application to molecules and solids • Hybrid methods : combine quantum and classical techniques for large systems Acquired skills By completing this lecture, students will gain the ability to:

- Choose appropriate level of theory to solve problems: accuracy versus computational cost
- Get geometries of molecular and solid structures using energy minimization techniques.
- Calculate spectroscopic properties: Infrared and Raman spectra, band structure, phonons
- Introduction to reactivity: get transition state structures, evaluate reaction rates

Modalités d'évaluation
Evaluation : isolée Report and oral defense

ADVANCED SPECTROSCOPY OF MOLECULAR SYSTEMS: FROM GAS PHASE TO CONDENSED MATTER (ASMS)

UE : ADVANCED SPECTROSCOPY OF MOLECULAR SYSTEMS: FROM GAS PHASE TO CONDENSED MATTER (ASMS)

BCC1: IMPLEMENTING FUNDAMENTAL PHYSICS TOOLS AND APPROACHES TO PRODUCE HIGHLY SPECIALIZED KNOWLEDGE

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Bertrand Chazallon* – bertrand.chazallon@univ-lille.fr
List of potential teachers: Bertrand Chazallon bertrand.chazallon@univ-lille.fr, Claire Pirim claire.pirim@univ-lille.fr, Dudognon Emeline emeline.dudognon@univ-lille.fr, Motiyenko Roman roman.motiienko@univ-lille.fr

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**12**		**15**		**27**

Required prior teaching unit(s):

Suggested readings:

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Syllabus :

This course aims to introduce fundamental principles in molecular physics characterization by optical (vibrational, rotational) and neutron spectroscopies, as well as dielectric techniques.

This course is situated within the framework of molecular physics and is intended for students pursuing research in molecular spectroscopy, gas-phase and condensed-phase molecular dynamics, and physical chemistry applied to environmental sciences, planetary sciences and pharmaceutics, with a strong physics foundation.

Objectives
1. Acquire theoretical understanding and practical insight into advanced spectroscopy methods.
2. Understand how molecules interact with photons, neutrons, and alternating electric fields.
3. Analyze and interpret vibrational, rotational, and dielectric spectra.
4. Connect spectroscopic signatures to the structural and dynamic properties of studied systems.

Course outline
Lecture 1: Optical and Neutron Scattering (Raman and Neutron Spectroscopy)

- Principles of inelastic scattering and selection rules.
- Experimental setups and spectral interpretation.

Applications in environmental science, planetary science, and pharmaceutics.

- Lecture 2: Absorption Spectroscopy (FTIR)
- Dipole-based infrared absorption and selection rules.
- Michelson interferometer operation and Fourier analysis.
- Identifying functional groups and molecular vibrations; applications across materials.

Lecture 3: Microwave Spectroscopy

- Rigid rotor model and rotational transitions.
- Analyzing rotational spectra to extract molecular parameters.
- Applications in astrophysics, atmospheric science, and molecular identification.

Lecture 4: Dielectric Spectroscopy

- Dielectric response to alternating electric fields.
- Relaxation processes and conductivity spectra.
- Applications to disordered systems and slow molecular dynamics.

Acquired skills
Direct skills:

- Interpret Raman, neutron, FTIR, microwave, and dielectric spectra.
- Optimize experimental parameters for specific samples.
- Extract molecular information using classical and quantum models.

Indirect skills:

- Compare light-, particle-, and field-based spectroscopic methods.
- Identify relevant techniques for addressing molecular-level questions in various phases.
- Understand the relationship between microstructure and spectroscopic signatures

Modalités d'évaluation

Evaluation : isolée

Written exam (75%) + reports on pratical on research instruments (25%)

FOREIGN LANGUAGE : ENGLISH OR FRENCH

UE : FOREIGN LANGUAGE

BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT

Choice-based classes
Teaching method: as required, remote or in person
Teaching language: as required

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours						

Required prior teaching unit(s):

Suggested readings:

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Syllabus :

Improve your communication skills in a foreign language

Modalités d'évaluation

CC, CT, rapport, soutenance orale,... + pondérations

INSTRUMENTATION IN SPECTROSCOPY

UE : SPECIALITY (PICK 3 OUT OF 5)

BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT

Choice-based classes
Teaching method: in person
Teaching language: English

Person in charge: *Manuel Goubet* – manuel.goubet@univ-lille.fr
List of potential teachers: Bertrand Chazallon bertrand.chazallon@univ-lille.fr, Cristian Focsa cristian.focsa@univ-lille.fr, Elias Neeman elias.neeman@univ-lille.fr, Claire Pirim claire.pirim@univ-lille.fr

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**10.5**				**10.5**

Required prior teaching unit(s):

Suggested readings:
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Syllabus :

Objectives
After a short reminder of the fundamentals of spectroscopy (energy level diagram, absorption, emission, diffusion), this course aims to present the various instrumentations, their principle and their characteristics, used to answer to questions in the domain of relevance (environmental sciences, astrophysics, energy, human health, drug design, fundamental physics, etc.).

Course outline
1. **Spectroscopy basics**: definitions, spectral ranges, energy diagram, transition probabilities, etc. **What information can we get from a spectrum**. (1.5h)
2. **Spectroscopic instrumentation**: sources, optics, detectors (4.5h)
3. **Sources** from the microwave to X-ray: synthetizer, lamps, lasers, synchrotron radiation, etc.
4. **Wavelength selection devices** from the microwave to X-ray: filters, gratings, monochromators, spectrometers, etc.
5. **Detectors** from the microwave to X-ray: transducers, diodes, photomultipliers, CCDs, etc.
6. **Examples of spectrometers and their applications.** (3h)
7. **Bibliographic review of a research article.** (1.5h)

Acquired skills
- Ability to describe and discuss radiation/matter interactions from both a simple theoretical and experimental perspective

- Understanding the physical concepts underlying modern scientific instrumentation
- Ability to recognize, analyze, and interpret basic results from experiments or simulations
- Ability to identify the appropriate instrumental technique necessary to answer a given scientific question.
- Ability to analyze and interpret scientific literature
- Clear and concise written scientific communication

Modalités d'évaluation

Evaluation : isolée
50 % written exam
50 % written report of bibliographic review

MATERIALS UNDER EXTREME CONDITIONS

UE : SPECIALITY (PICK 3 OUT OF 5)

BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT

Choice-based classes
Teaching method: in person
Teaching language: English

Person in charge: *Sébastien Merkel* – sebastien.merkel@univ-lille.fr

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**10.5**				**10.5**

Required prior teaching unit(s):

Suggested readings:

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Syllabus :

Pressure and temperature have a drastic effect of the physical properties of mater. Simple H2O, for instance, can show more that 10 different crystalline phases when playing with P and T. This class will highlight the fundamentals of high pressure physics with applications in condensed matter, materials, and planetary sciences.

Objectives
This class will analyze the state of matter under extreme conditions, from planetary interiors to high velocity impacts. Students will learn about emerging topics on the physics of matter under pressure and temperature, fundamentals of high-pressure thermodynamics, and experimental methods used to address those questions in laboratories.

Course outline

1. Introduction
   Extreme conditions in the Universe and technological applications. Scales of pressure and temperature.
2. Experimental techniques and metrology
   Static and dynamic experiments
   In-situ characteristization methods
   Large-scale international facilities for extreme conditions experiments
   Lab tour
3. Thermodynamics
   Pressure in phase diagrams
   Equations of state
   Phase transitions

Melting
Exotic states of matter

4. Applications
Fundamental physics : supraconductivity, simple elements, etc
Materials science: ultrahard materials, superionic materials, etc
Earth and planets: state of matter in planetary interiors
5. Project
Analysis and study of a paper from the scientific literature. Presentation and explanation to others in the form of a class for master students.

Acquired skills

- Conduct a scientific and technical analysis based on a bibliographical search in recent publications in the scientific literature
- Predict and interpret the effects of pressure and temperature on the properties of matter
- Apply acquired knowledge of the physics of materials and molecules to materials under extreme conditions

Modalités d'évaluation

Evaluation : isolée
Final exam (50%) and project (50%)

MATHEMATICAL CRYSTALLOGRAPHY

UE : SPECIALITY (PICK 3 OUT OF 5)

BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT

Choice-based classes
Teaching method: in person
Teaching language: English

Person in charge: *Damien Jacob* – damien.jacob@univ-lille.fr
List of potential teachers: D. Jacob, S. Merkel

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**10.5**				**10.5**

Required prior teaching unit(s):

Suggested readings:

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Syllabus :

The matrices formalism and simple algebraic mathematics are very useful in crystallography for determining the relationships between planes and directions, symmetry operations, coordinate transformations, and conversions from direct to reciprocal space.

Objectives
This lecture is an introduction to the use of matrice's mathematics for solving numerous problems of crystallography in condensed matter sciences. The aim is to be able to handling spatial coordinates transformation associated to symmetry operations or changing of crystal's framework, both in direct and reciprocal space. Representation of crystal's orientation in three dimensions using sterographic projection are also covered.

Course outline
1. Basics of crystallography : unit cell content, lattice and symmetry
2. Points, vectors and Matrices
3. Coordinate transformation
4. Crystallographic symmetry
5. Crystal representation and stereographic projection
6. Direct and reciprocal space relationships
7. Applications and experiments

Acquired skills

- Develop advanced experiments in crystallography
- Connect mathematical tools and matrix operations for advanced calculations and experiments on crystals

Modalités d'évaluation

Evaluation : isolée
Final exam (50%) and project's report (50%)

METALS AND ALLOYS

UE : SPECIALITY (PICK 3 OUT OF 5)

BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT

Choice-based classes
Teaching method: in person
Teaching language: English

Person in charge: *Franck Béclin* – franck.beclin@univ-lille.fr

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**10.5**				**10.5**

Required prior teaching unit(s):

Suggested readings:

-

Syllabus :

Discover elements of research in physical metallurgy, from fundamental research to real world applications

Objectives
The course is intended to introduce current topics and provide students with the missing background to enter research teams in the field of physical metallurgy. The student will understand the thermodynamic processes involved in heat treatments designed to optimize the microstructure of metallic alloys. The relationship between microstructure and properties in use will be explained.

Course outline
1. Thermodynamics and Phase Diagrams
2. Martensitic transformation
3. Solidification route, precipitate growth
4. Recrystallization
5. Project
   Analysis and study of a paper from the scientific literature. Presentation and explanation to others in the form of a class for master students.

Acquired skills
- Conduct a scientific and technical analysis based on a bibliographical search in recent publications in the scientific literature
- Apply acquired knowledge of the physics of metals and their real world research applications

Modalités d'évaluation

Evaluation : isolée
Final exam (50%) and project (50%)

POLYMERS

UE : SPECIALITY (PICK 3 OUT OF 5)

BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT

Choice-based classes
Teaching method: in person
Teaching language: English

Person in charge: *Tiana Deplancke* – tiana.deplancke@univ-lille.fr
List of potential teachers: Valérie Gaucher, Tiana Deplancke, Sophie Barrau

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		10.5				10.5

Required prior teaching unit(s):

Suggested readings:

-

Syllabus :

Gain insights into the structure-property relationships of polymer materials and understand essential characterization and processing techniques. Learn to select the polymer in relation to use properties.

Objectives
This course is designed to introduce the main techniques for processing polymer materials, the microstructures obtained and the properties that depend on them. In order to establish the links between microstructure and properties (mechanical, physical, etc.), various mechanical testing and microstructural characterization techniques will be covered, as well as their analysis.

Course outline
1. Class 1 (2H CTD) : Remember what a polymer is and the different types of polymers (thermoplastics, elastomers, thermosets) and phase transitions (which they also see in thermodynamics and are introduced in S1 in Intro to Materials).
2. Class 2 (2H CTD): Elasticity and viscoelasticity → simple rheological models
3. Class 3 (2H CTD): Processing techniques based on phase transitions
4. Class 4 (2H CTD): Non-linear behavior (from tensile curves to models?)
5. Class 5 (2H CTD): Example of a simple case study (guessing the type of polymer based on several experimental results) in preparation for the oral exam and selection of bibliographic projects.

Acquired skills
Upon completing this course, students will have the ability to determine the structure-property relationships

of polymer materials through experimental findings. They will be well-versed in key characterization and processing methods. Additionally, students will be able to select the polymer and processing method, understand and analyze characterization techniques in relation to desired use properties.

Modalités d'évaluation

Evaluation : isolée
Project (1/3) Oral (1/3) Exam (1/3)

ADVANCED THERMODYNAMICS AND PHASE TRANSFORMATIONS

UE : ADVANCED THERMODYNAMICS AND PHASE TRANSFORMATIONS
BCC3: SOLVING COMPLEX PROBLEMS BY APPLYING FUNDAMENTAL PHYSICS CONCEPTS

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Frédéric Affouard* – frederic.affouard@univ-lille.fr

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**24**				**24**

Required prior teaching unit(s):

Suggested readings:
-

Syllabus :

This course explores the principles governing crystalline and amorphous physical states and their transformations across diverse materials like metallic alloys, glasses, and polymers.

Objectives
The course provides the theoretical basis for understanding equilibrium and out-of-equilibrium condensed physical states and their transformations (crystallization/melting, amorphisation, phase separation) under various stresses (pressure, temperature, milling, dehydration) in a wide range of existing materials (metallic alloys, organic/inorganic glasses, polymers).

Course outline
- Thermodynamics of single-component systems (reminders): Physical states (crystalline polymorphs and amorphous forms). Stability, metastability, and instability. Calorimetric experimental method to probe transformations.
- Thermodynamics of multicomponent systems: Construction and interpretation of binary phase diagrams. Gibbs free energy diagrams as a function of mixture composition. Binodal & spinodal. Precipitations. Eutectic systems. Miscibility, and solubility.
- Dynamics of phase transitions: Nucleation and growth. Interfaces. Avrami model. Time-Temperature-Transformation (TTT) diagrams. Spinodal decomposition. Cahn–Hilliard equation.
- Thermodynamics of the glassy states and glass transition: Duality crystal vs glass. Kinetic vs thermodynamic transition. Enthalpy, heat capacity and entropy functions in the glass transition region. Kauzmann Paradox. Good and poor glass-forming materials. Conditions for glass formation. Thermal and a-thermal techniques to obtain a glass. Modern theories of glasses.

Acquired skills

On successful completion of the course students will be able to:

1. To know the different physical states and the transformations of the main classes of existing materials
2. Construct, describe and interpret a phase diagram from Gibbs energy for single-component and multicomponent systems
3. Describe the theoretical basis for, be able to formulate and apply classical models for phase transformations (crystallization, melting, vitrification) and be able to make use of this knowledge to carry out relevant quantitative calculations
4. Know the basic principles of calorimetric techniques for the study of phase transformations

Modalités d'évaluation

Evaluation : isolée
1 final written exam

MOLECULAR MOBILITY AND AMORPHOUS STATE OF MATTER

UE : MOLECULAR MOBILITY AND AMORPHOUS STATE OF MATTER
BCC3: SOLVING COMPLEX PROBLEMS BY APPLYING FUNDAMENTAL PHYSICS CONCEPTS

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Emeline Dudognon* – emeline.dudognon@univ-lille.fr

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**24**				**24**

Required prior teaching unit(s):

Suggested readings:
-

Syllabus :

This course presents the characteristics of molecular motions found in amorphous materials in the supercooled and glassy states, and the temperature dependence of these dynamics.

Objectives
This course provides an overview of the different types of molecular mobilities characterising the glass-forming liquids and some mesophases (wide amplitude motions, localised motions of intra- or inter-molecular origins), and their properties. It also introduces the main techniques used to characterise these dynamics. The objective is to be able to identify and analyse the different relaxational processes encountered in the glassy and supercooled liquid states.

Course outline
5. Introduction: spatial and temporal scales of the different types of motions, fluctuation/dissipation theorem; Short reminders about the different structural organisations of materials (crystals, mesophases, glasses)
6. Technics allowing the study of molecular mobility: dielectric relaxation spectroscopy, thermo-stimulated currents, dynamic mechanical analysis
7. Dynamics of glass-forming liquids: main dynamics (fingerprints, non-Arrhenius behaviour and non-exponentiality), secondary relaxations of intra- and inter- molecular origins, relaxations beyond the main relaxation, non-linearity of relaxations in the glassy state, Case studies
8. Relaxations in semi-crystalline materials and some mesophases.

Acquired skills
On successful completion of the course, students will be able to:
- identify the different types of glass-forming liquids,
- know the basic principles of relaxation spectroscopies (DRS, DMA),

- analyse a relaxation spectrum,
- construct, describe and interpret an Arrhenius diagram,
- identify a dynamic process by the determination of the associated relaxation time, its behaviour law and its activation energy,
- make use of their knowledge of relaxational processes to determine the influence of the dynamics on the molecular properties of amorphous materials.

Modalités d'évaluation

Evaluation : isolée
1 final written exam

FROM MACRO TO NANOPHYSICS

UE : FROM MACRO TO NANOPHYSICS

BCC3: SOLVING COMPLEX PROBLEMS BY APPLYING FUNDAMENTAL PHYSICS CONCEPTS

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Gaëtan Lévêque* – gaetan.leveque@univ-lille.fr
List of potential teachers: G. Lévêque, Y. Pennec, A. Akjouj

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**24**				**24**

Required prior teaching unit(s):

Suggested readings:

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Syllabus :

Introduce the physics of nanomaterials, and show how optical / electromagnetic / thermal / mechanical properties are modified from macroscopic to the nanometer scale.

Objectives

Identify the physical mechanisms involved in the polarization of dielectrics. Understand how the physical properties of materials are modified at the nanoscale. Plasmons, QD, confinement of light at the nanoscale, heat nanosource, nanocomposite, 2D materials.

Course outline

9. Mechanisms of polarization (electronic, ionic, orientational polarisation) - 6h
10. Description of nanomaterials (0D, 1D, 2D), surface/volume effect, hierarchy of physical interactions according to their dimensionality. Synthesis of nanosystems (bottom-up/ top-down approach) - 2h
11. Optical properties of nanoparticles, polarisability of nanoparticles in elecrostatic approximation, Mie and Rayleigh Gans theory - 2h
12. Plasmonic effects: localized and delocalized surface plasmons. Confinement and exaltation of light. Applications: SERS, luminescence, fluorescence enhancement, sensing, display and generation of colors, photovoltaics… - 3h
13. Thermal effects at the nanoscale and applications (thermodynamics, thermal-induced processes, applications) - 3h
14. Mechanical properties of nanomaterials – 4h

Acquired skills

Modalités d'évaluation

Evaluation : isolée
CC, CT, rapport, soutenance orale,... + pondérations

MATERIALS PLASTICITY

UE : MATERIALS PLASTICITY

BCC3: SOLVING COMPLEX PROBLEMS BY APPLYING FUNDAMENTAL PHYSICS CONCEPTS

Mendatory class
Teaching method: in person
Teaching language: English

Person in charge: *Philippe Carrez* – philippe.carrez@univ-lille.fr

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours		**24**				**24**

Required prior teaching unit(s):

Suggested readings:

15. Imperfections in Crystalline Solids, W. Cai & W.D. Nix MRS-Cambridge Materials Fundamentals

Syllabus :

Physical basis of plasticity of crystalline solids, from the elementary mechanisms to the plastic behavior in various conditions

Objectives
The scope of this course is to give an overview of the plastic behavior of crystalline solids, through a presentation of the elementary mecanisms of dislocation motion and interaction.

Course outline
- Basic review of defects in crystalline solids
- Low temperature deformation : Franck-Read source, dislocation motions and interactions, hardening
- Origin of hardening : forest hardening, dislocation pile up, grain boundaries, alloying and precipitates
- High temperature deformation : Newtonian and non newtonian creep

Acquired skills
Students will not only know how defect behave in crystalline materials but also should be able to apply fundamental principles to explain mechanical behaviors, make predictions or analyze mechanical situations of solid materials they may encounter in the future.

Modalités d'évaluation

Evaluation : isolée
1 CT

CLASSES IN SEMESTER S4

List of acronyms:

- BCC: Bloc de Compétence et Compétence = teaching block
- UE: Unité d'Enseignement = teaching unit
- CM: Cours magistral = main class
- TD: Travaux Dirigés = practicals
- C-TD: Cours-TD = mix of classes and practicals
- TP: Travaux Pratiques = labs

PE OR GRADUATE PROGRAM SPECIAL TEACHING

UE : PE OR GP

BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT

Choice-based classes
Teaching method: as required, remote or in person
Teaching language: as required

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours						

Required prior teaching unit(s):

Suggested readings:

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Syllabus :

Learn on current topic from the Materials for a Sustainable Future graduate program

Modalités d'évaluation

CC, CT, rapport, soutenance orale,... + pondérations

INTERNSHIP

UE : INTERNSHIP

BCC2: PRODUCING AND COMMUNICATING HIGHLY SPECIALIZED KNOWLEDGE, INCLUDING IN A PROFESSIONAL CONTEXT

Mendatory class
Teaching method: in person
Teaching language: as required

Teaching volume	CM	C-TD	TD	TP	Remote	Total
Supervised teaching hours						

Required prior teaching unit(s):

Suggested readings:

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Syllabus :

A five-month-long experience in a professional working environment

Modalités d'évaluation

Evaluation : isolée
CC, CT, rapport, soutenance orale,... + pondérations