Master of Science in Physics - Master of Science in Physics

Semester 1

	Lecture (UE)	Exercise (UE)	ECTS
Module 1.1			6
Solid State Physics	70	20	6
Module 1.2			4
Physics of Living Matter	30	15	4
Module 1.3			4
Computational Methods	30	15	4
Module 1.4			4
Colloids and Liquid Crystals	30	15	4
Module 1.5			4
Laser Physics	30	15	4
Module 1.6			4
Classical and Quantum Information Theory	45		4
Module 1.7			2
Advanced Materials Characterization Techniques	30		2
Module 1.8			0
Partial Differential Equations I (Optional)	30	30	8
Discrete-time stochastic processes (Optional)	30	15	6
111 Lernen und schulisches Lernen (Optional)	30		4
ISB701: Introduction to Systems Biology (Optional)	30	40	4
Physics didactics 1 (Optional)	30		3
Computational Fluid Dynamics (Optional)	30		3
Communicating science (Optional)	24		3

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	Lecture (UE)	Exercise (UE)	ECTS
Academic English B2 (Optional)	30		3

Semester 2

	Lecture (UE)	Exercise (UE)	ECTS
Module 2.1			4
Ferroelectrics and multiferroics	30	15	4
Module 2.2			4
Introduction to General Relativity	30		4
Module 2.3			4
Classical and Quantum Transport	30	15	4
Module 2.4			4
Semiconductors and Solar Cells	30	15	4
Module 2.5			4
Nonequilibrium soft and active matter	30		4
Module 2.6			6
Lab class		120	6
Module 2.7			2
Literature Seminar	30		2
Module 2.8			0
Partial Differential Equations II (Optional)	30	30	8
Principles of Software Development (Optional)	30	15	5
Knowledge Discovery and Data Mining (Optional)	30	15	5
Didactics for Physics 2 (Optional)	30		3

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	Lecture (UE)	Exercise (UE)	ECTS
Advanced engineering materials (Optional)	45		4

Semester 3

	Lecture (UE)	Exercise (UE)	ECTS
Module 3.1			30
Lab Class in Preparation for Master Thesis	375		27
Seminar on the Master Thesis Topic	30		3

Semester 4

	Lecture (UE)	Exercise (UE)	ECTS
Module 4.1			30
Master Thesis		375	20
Defense of Master Project	30		10

Semester 1

Solid State Physics

Module: Module 1.1 (Semester 1)

ECTS: 6

Objective: The course introduces the students to the atomic and electronic structure of solid crystalline materials. The goal of solid-state physics is to understand the macroscopic properties (such as hardness, color, electrical conductivity, heat capacity, etc.) from the microscopic structure of the material. The lattice dynamics (phonons) of crystalline materials will be studied in oder to understand the thermal properties of matter. The electronic structure of metals, semiconductors, and insulators will be treated in detail, as well as their optical properties.

Course learning outcomes: A student who passes this course will be able to:
- explain the most common crystal structures and their determination by X-ray scattering
- describe the reaction of crystals to various stresses
- understand the storage and transport of heat in solids
- explain the difference between metals, semiconductors and insulators based on their electronic structure
- understand the link between optical properties and electronic excitations

The course will enable the student to study the literature on current research topics in the field of solid-state physics.

Description:
• crystal structures (reciprocal lattice, X-ray diffraction, crystal bonds, crystal defects)
• elastic properties (continuum mechanics, elastic tensors)
• phonons (quantisation, dispersion, Debye and Einstein model, specific heat and heat conduction)
• electrons (band structure, Sommerfeld model, Bloch functions, quasi free electrons, tight binding model, defects in semiconductors)
• solid state optics (model dielectric functions, electronic transitions)
• superconductivity

Teaching modality: Lecture + TD

Language: Anglais

Mandatory: Oui

Evaluation: TD and oral exam

Remark: Support :
Lecture Slides
Literature :
- C. Kittel, Introduction to Solid State Physics, Wiley
- H. Ibach and H. Lüth, Solid-State Physics, An Introduction to Principles of Materials Science,Springer

- N.W. Ashcroft and N.D. Mermin, Solid State Physics, Saunders College Publishing
- Rudolf Gross, Achim Marx, Festkörperphysik, Oldenbourg Verlag (in German)
- P. Yu and M. Cardona, Fundamentals of Semiconductors: Physics and Materials Properties, Springer
- K. Kopitzki, Einführung in die Festkörperphysik, Teubner (in German)
- G. Burns, Solid State Physics, Academic Press, used only

Professor: DALE Phillip, REDINGER Alex, ROMMELFANGEN Jonathan

Physics of Living Matter

Module: Module 1.2 (Semester 1)

ECTS: 4

Objective: Cross Disciplinary course in Biological Physics targeted to Masters and PhD level students from PhyMS RU, LS RU, LCSB, RU ES, LIH, and LIST.
The cross-disciplinary field of biophysics has seen major expansion in the recent years, thanks to the advancements in physical, engineering and computational tools. Luxembourg is at the forefront of scientific activities in biological physics with its exciting landscape of experimental and theoretical research on biological questions that require a strong quantitative physical approach. The Physics and Materials Research Unit offers an introduction to this exciting interdisciplinary field, interfacing fluid mechanics, microbiology (of virus, bacteria, and algae), physical ecology, and materials physics. This course will explore how quantitative approaches in biological sciences could provide a mechanistic framework for the rich myriad of emergent phenomena observed in living systems.
Main Objectives
1. To be able to quantify biological processes at the level of individual cells, populations, and multi-species communities, and their relation to the environments they inhabit.
2. To have an overview of the main relevant experimental and statistical tools, and respective working principles, relevance, and limitations.
3. To understand cross-interactions between cellular behavior and physiology.
4. To understand how single cell dynamics lead to emergent functional properties at the scale of population and communities.

Course learning outcomes: A student who passes this course will be able to:
- Identify and quantitatively analyze biological systems and their dynamics, and suggest underlying physical principles driving biological functions.
- Propose appropriate methods and tools for tracking and analyzing biological processes, and comment on the statistical significance of the obtained data.
- Analyze the impact of changes in the environmental conditions, whether induced artificially or due to natural patterns in the ecosystem.
- Identify original problems from biological systems, relevant from environmental and human sciences, and develop testable hypotheses toward investigating these open questions.
This course will enable the student to read, understand, and analyze academic literature related to biological physics in a wide range of contexts. The course provides a fundamental basis to follow more advanced courses in biophysics, in particular those related to biological transport processes, emergent phenomena and the inter-relation of form and function in biology.

Description: Core Topics

	- Physics of cell: random walks, transport processes, molecular motors, and active matter - Life at micro-scales; fluctuations and dissipation in the cell - Scaling up single cell physics to population and community scales - Living in fluctuating environments Tools and Techniques - Live cell imaging, spectroscopy, and image analysis - Microfluidics, micromanipulation, and optical techniques - Complex systems approach: probabilistic, deterministic, and network analyses - Biostatistics: Statistical tools and inference in biological systems
Teaching modality:	Lecture and Tutorial & Discussions
Language:	Anglais
Mandatory:	Oui
Evaluation:	Tutorial & Discussions, powerpoint presentations, and oral exam
Remark:	Support : Lecture slides available on the course website Literature : Relevant course books: Physical Biology of the Cell by Phillips, Kondev, Theriot and Garcia (ISBN: 0815344503) Random Walks in Biology by Howard C Berg (ISBN: 0691000646) E. coli in motion by Howard C Berg (ISBN: 978-0387008882) A Mechanistic Approach to Plankton Ecology by Thomas Kiørboe (ISBN: 978-0691134222)
Professor:	SENGUPTA Anupam, ONG Irvine

Computational Methods

Module:	Module 1.3 (Semester 1)
ECTS:	4
Objective:	The main idea of the course is to provide knowledge and practical experience of the numerical techniques that constitute the basis of Computational Physics and Chemistry. Each lecture will be comprised of an introduction to the theory behind a given technique, followed by a practical session centered on its implementation and application for well-known problems. Some emphasis will be put on the analysis of the outcome of the variation of physical parameters for the given problem. The first part of the course will consolidate simple notions of python3 programming and cover the basic algorithms necessary to solve simple equations. The second part will provide an introduction on more advanced methods such as Monte Carlo and Machine Learning, as well as cover the numerical solution of the time-dependent Schrödinger equation and molecular dynamics.
Course learning outcomes:	• knowledge of standard algorithms adopted in computational Physics and Chemistry and their limitations • capability of writing a program to find the numerical solution of simple physical problems and analyze the resulting data • understanding the basics of Monte Carlo methods, molecular dynamics simulations and machine learning

Language: Anglais

Mandatory: Oui

Evaluation: TD

Remark:
1. Numerical Methods for Scientists and Engineers, Richard W. Hamming (Dover publications)
2. Numerical Recipes series, William H. Press, Saul A. Teukolsky, William T. Vetterling and Brian P. Flannery (Cambridge university press)
3. Numerical Methods, E. A. Volkov (Hemisphere publishing corporation)
4. https://www.codecademy.com/learn/learn-python-3
5. https://www.learnpython.org/en/

Professor: TKATCHENKO Alexandre, KHABIBRAKHMANOV Almaz, GALANTE Mario

Colloids and Liquid Crystals

Module: Module 1.4 (Semester 1)

ECTS: 4

Objective: The objective of this course is to introduce students to the world of colloids and liquid crystals and make them discover these soft states of matter with their distinctive and useful physical properties.
Main Objectives
1. To understand what a liquid crystal is and the consequences of its anisotropic properties;
2. To be able to identify colloidal systems, understand the key colloidal scale interactions and the physics of colloid stabilization and destabilization;
3. To account for the various self-assembly/self-organization processes that take place in colloidal dispersions and liquid crystals, correlating nano- and microstructure with macroscopic properties;
4. To get acquainted with the theories for describing colloids and liquid crystals;
5. To get an overview of the main relevant preparation and characterization tools and their respective working principles, advantages and limitations.

Course learning outcomes: A student who passes this course will be able to:
- Identify liquid crystalline and colloidal systems and describe, prepare and analyze them using the proper physics and physical chemistry tools, both in terms of concepts and experimental equipment;
- Explain the characteristics of the two main classes of liquid crystals and account for their typical phase behavior in response to relevant thermodynamic control parameters.
- Describe the concept of liquid crystal director and account for its relation to macroscopic properties, its interaction with electric and magnetic fields, as well as the consequences of director field deformations.
- Master the concept of an order parameter and apply it to describe phase transitions as well as to correlate characteristics on the molecular and macroscopic scales.
- Elucidate the propagation of light in liquid crystals and colloids, in particular considering anisotropy (birefringence), periodic internal structures (structural color) and refractive index heterogeneity (scattering).
- Illustrate the basic mechanism of function of liquid crystal displays.

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- Define the conditions for colloidal stability or instability, accounting for the effect of salts.
- Account for the impact of colloid dispersity and how it can be reduced by fractionation.

This course will enable the student to read the academic literature dealing with the fundamental properties of liquid crystals and colloids. It also provides a firm basis to follow more advanced courses in soft condensed matter.

Description:

- Definition of colloids and liquid crystals and the key concepts for describing them.
- Overview of liquid crystal classes (thermotropic/lyotropic) and phases (nematic, cholesteric, smectic, …) and colloid types (associated/unassociated, suspensions, emulsions, gels, …).
- Self-assembly and self-organization.
- Basics of optics of anisotropic media and application to the case of liquid crystals.
- Liquid crystal elasticity and topological defects.
- Dielectric/magnetic properties of liquid crystals; response to electric/magnetic fields.
- Design and function of liquid crystal displays (LCDs).
- Chiral systems and their peculiar properties.
- Key colloidal interactions: van der Waals attraction (and analysis by the Hamaker approach), hydrogen bonding, hydrophobic effect, electrostatic interactions in liquids, capillary forces.
- Poisson-Boltzmann and DLVO theories; electrostatic double layer, Debye screening length, hydrodynamic radius, Zeta potential, ionic strength, electrostatic screening.
- Steric versus electrostatic stabilization. Destabilization using salt, polymer bridging or depletion attraction. Sedimentation, centrifugation and flocculation.
- Solvent evaporation, wetting, and the effects of capillary forces. Ostwald ripening.
- Experimental methods for investigating colloids and liquid crystals and their properties.

Teaching modality: Lecture and TD

Language: Anglais

Mandatory: Oui

Evaluation: TD, mid-term exam and oral final exam

Remark:

Support :
Lecture slides available on Moodle

Literature :
Main course books:
Introduction to Liquid Crystals: Chemistry and Physics, by Peter J. Collings, Michael Hird, CRC Press, ISBN-13: 9780748404834 - CAT# TF1996
"An Introduction to Interfaces & Colloids; The bridge to Nanoscience" by John C. Berg, World Scientific Press, ISBN-13: 978-981-4293-07-5
Support books for specific topics:
The Physics of Liquid Crystals by P.G. de Gennes, J. Prost, Oxford University Press, ISBN-13: 978-0198517856
"Intermolecular And Surface Forces" by Jacob Israelachvili, Academic Press, ISBN: 0123751829

Professor: SCALIA Giusy

Laser Physics

Module: Module 1.5 (Semester 1)

ECTS: 4

Objective: The objective of this course is to introduce students to lasers and the fundamental concepts in optics and physics that are at the basis of their operations.
Main Objectives
1. To understand what is a laser and how it works
2. To understand the properties of a laser beam
3. To know fundamental aspects of interaction between light and matter
4. To learn what are the principal uses of lasers in a scientific environment
5. To understand different type of lasers and different regimes of operation
6. To introduce nonlinear optics

Course learning outcomes: A student who passes this course will be able to:
- Describe the physical processes that make possible a laser
- Explain what are the fundamental ingredients in a laser and what is their role in the lasing action
- Describe the propagation of a laser beam
- Elucidate the coherence properties of the light emitted by a laser
- Describe the continuous and pulsed operation regimes
- List typical laser and explain their peculiarities
- Explain the fundamental aspects of nonlinear optics
- Describe the main scientific applications of laser light

This course will enable the student to read the academic literature dealing with laser physics and acquire knowledge useful in advanced courses of optics and photonics.

Description:
- Spontaneous and stimulated emission
- Gain media and rate equations
- Laser cavity and relative modes
- Solid state lasers
- Gas lasers
- Semiconducting lasers
- Coherence of laser radiation
- Propagation of a Gaussian beam
- Q-switching and mode locking
- Introduction to nonlinear optics
- Lasers in science

Teaching modality: Lecture and TD

Language: Anglais

Mandatory: Oui

Evaluation: TD, powerpoint presentations, and oral exam

Remark: Support :
Lecture slides
Literature :
Book:
Principles of Lasers, by O. Svelto, Springer, ISBN 978-1-4419-1302-9
Advanced Book:
Ultrafast Optics, by A.M. Weiner, Wiley, ISBN 978-0-471-41539-8

Professor: BRIDA Daniele, ROJAS AEDO Ricardo Arturo

Classical and Quantum Information Theory

Module: Module 1.6 (Semester 1)

ECTS: 4

Description: Over the last decades, physics has evolved to identify the role of information as a unifying umbrella, transforming the understanding of biophysics, statistical mechanics, and condensed matter theory. Quantum Information theory has emerged as a new field merging physics, information theory, and computer science.

Th is course cover elem e nts of information theory both in the classical and quantum level. The first part introduces the elements of the classical theory, presenting essential topics such as information measures, channel capacity, hypothesis testing, complexity and information geometry. The second part focuses on the quantum information science, including measurement theory, quantum metrology, quantum information processing, and quantum computation.

Teaching modality: Lecture and TD

Language: Anglais

Mandatory: Oui

Remark: References:
J. A. Thomas and T. M. Cover, Elements of Information Theory , 2nd ed. (Wiley , 2006)

Isaac Chuang, Michael Nielsen, Quantum Computation and Quantum Information (Cambridge, 2000).

Professor: DEL CAMPO ECHEVARRIA Adolfo, POLETTINI Matteo

Advanced Materials Characterization Techniques

Module: Module 1.7 (Semester 1)

ECTS: 2

Objective:	This course aims at introducing the students to the background of several advanced experimental methods in Solid State and Materials Physics
Course learning outcomes:	The student who passes this course will be able: - to describe the theoretical background of the discussed methods - to apply the methods to concrete problems in solid state and materials physics
Description:	1. Phonon spectroscopy a) Raman spectroscopy b) Infrared spectroscopies c) Inelastic neutron and X-ray scattering d) Introduction to Group Theory for phonon spectroscopy 2. Photo-electron spectroscopy a) X-ray and UV Photon-Spectroscopy b) Auger Spectroscopy 3. Nano- and atomic scale imaging and analysis a) Introduction to charged particle optics b) Electron microscopy (SEM & TEM) c) Secondary Ion Mass Spectroscopy (SIMS) d) Atom Probe Tomography (APT) e) Helium Ion Microscopy (HIM)
Teaching modality:	Lecture
Language:	Anglais
Mandatory:	Oui
Evaluation:	Oral examination (30 minutes)
Remark:	Support : PowerPoint presentation (distributed before lecture)
Professor:	KREISEL Jens, WIRTZ Tom

Partial Differential Equations I

Module:	Module 1.8 (Semester 1)
ECTS:	8
Objective:	The goal of the course it to get acquainted with Partial differential equations (PDE) as a powerful tool for modeling problems in science, providing functional analytic techniques in order to deal with PDE.
Course learning outcomes:	On successful completion of the course the student should be able to: • Apply methods of Fourier Analysis to the discussion of constant coefficient differential equations • Work freely with the classical formulas in dealing with boundary value problems for the Laplace equation • Prove acquaintance with the basic properties of harmonic functions (maximum principle, mean value property) and solutions of the wave equation (Huygens property) • Solve Cauchy problems for the heat and the wave equations

- Give a pedagogic talk for peers on a related topic

Description:	Fourier transform, the classical equations, spectral theory of unbounded operators, distributions, fundamental solutions.
Teaching modality:	Lecture course
Language:	Anglais
Mandatory:	Non
Evaluation:	Written exam
Remark:	1. Rudin: Functional analysis 2. Jost: Postmodern analysis 3. Folland: Introduction to partial differential equations. 4. Reed-Simon: Methods of mathematical physics I-IV
Professor:	OLBRICH Martin, GROTTO Francesco, EL EMAM Christian

Discrete-time stochastic processes

Module:	Module 1.8 (Semester 1)
ECTS:	6
Objective:	Introduction to basic concepts of modern probability theory
Course learning outcomes:	On successful completion of the course, the student should be able to: • Understand and use concepts of modern probability theory (e.g., filtrations, martingales, stopping times) • Apply the notion of martingale to model random evolutions • Know and apply classical martingale convergence theorems • Describe and manipulate basic properties of Brownian motion
Description:	Filtrations, conditional expectations, martingales, stopping times, optional stopping, Doob inequalities, martingale convergence theorems, canonical processes, Markov semigroups and processes, Brownian motion.
Teaching modality:	Lecture course
Language:	Anglais
Mandatory:	Non
Evaluation:	Written exam
Remark:	H. Bauer, Wahrscheinlichkeitstheorie D. Williams, Probability with Martingales
Professor:	PILIPAUSKAITE Vytauté

111 Lernen und schulisches Lernen

Module: Module 1.8 (Semester 1)

ECTS: 4

Course learning outcomes:
Nach Abschluss der Vorlesungsreihe können die Studierenden
- Grundprinzipien, Konzepte, Gemeinsamkeiten bzw. Unterschiede der klassischen und aktuellen Lerntheorien beschreiben;
- menschliches Lernen in seiner Besonderheit verstehen;
- erörtern, wie Schulkinder (voneinander) lernen;
- behandelte Konzepte an Beispielen aus dem schulischen Alltag anwenden;
- Lehr/Lernarrangements in einen lerntheoretischen Rahmen stellen;

Description:
Der Kurs bietet einen Überblick über das komplexe Themenfeld „Lernen in der Schule". Folgende lerntheoretischen Zugänge und Strömungen aus unterschiedlichen disziplinären sowie interdisziplinären Kontexten werden in der Vorlesung vorgestellt und diskutiert:
- behavioristischer Ansatz
- kognitivistischer Ansatz
- konstruktivistische Ansätze
- neurobiologische Ansätze
- soziokonstruktivistische/soziokulturelle Ansätze
- erziehungswissenschaftliche/pädagogische Ansätze

Bibliographie:

- Giordan, A. (2016). Apprendre ! Paris : Editions Belin.
- Kölbl, C. (2006). Die Psychologie der kulturhistorischen Schule. Vygotskij, Lurija, Leont'ev. Göttingen: Vandenhoeck & Ruprecht.
- Sunnen, P. (2011). Lernen. Ausführungen zum erziehungswissenschaftlichen Lernbegriff bei Gerold Scholz. In H. de Boer, H. Deckert-Peaceman & K. Westphal (Hg.), Irritationen – Befremdungen – Entgrenzungen. Fragen an die Grundschulforschung (S. 191-215). Frankfurt/Main: Goethe Universität Frankfurt/Main.
- Vosniadou, S. (2001). How children learn. Educational Practices Series, 7. Geneva: International Academy of Education, International Bureau of Education.
- Winkel, S., Peterman, F., & Peterman, U. (2006). Lernpsychologie. Paderborn: UTB.

Weitere Literatur wird in der Vorlesung bekanntgegeben.

Language: Allemand, Français, Anglais

Mandatory: Non

Evaluation: Klausur

Professor: SUNNEN Patrick

ISB701: Introduction to Systems Biology

Module:	Module 1.8 (Semester 1)
ECTS:	4
Objective:	Getting an overview on the elements of systems biology and its concepts Ability to analyze biological processes by systems biology methods and concepts Understanding of the principles of systems biology, such as topology, stochiometrics and kinetics
Course learning outcomes:	1. Recall and apply key procedures and methods in mathematics and bioinformatics. 2. Differentiate the key principles of bottom-up systems biology. 3. Integrate basic understanding of bottom-up systems biology by designing, creating and analyzing models.
Description:	Definition of systems biology Basic concepts in systems biology Biophysical basis of enzyme reactions Reconstruction of biochemical networks Metabolic networks Basic features of the stoichiometric matrix Topological properties
Teaching modality:	Lectures
Language:	Anglais
Mandatory:	Non
Evaluation:	Written exam
Remark:	**Learning material:** Lecture slides, PDF-files of review articles
Professor:	SAUTER Thomas

Physics didactics 1

Module:	Module 1.8 (Semester 1)
ECTS:	3
Objective:	• découvrir la richesse de l'enseignement de la physique • planifier et vivre des situations d'enseignement en classe

- planifier des expériences de démonstration
- analyser ses propres performances pour mieux s'orienter dans son choix professionnel
- comprendre l'enseigenement de la physque au secondaire et secondaire technique

Course learning outcomes:	Connaître les multiples facettes de l'apprentissage et de l'enseignement de la physique et les défis posés à l'enseignant.
Teaching modality:	cours magistraux, travail indépendant, travaux pratiques, travaux dirigés La connaissance et la maîtrise de ces deux langues (Français & Deutsch) est requise
Language:	Français, Allemand
Mandatory:	Non
Evaluation:	La présence à tous les cours est obligatoire. Engagement régulier, élaboration d'un portfolio personnel (pièces créées à partir des éléments traités en cours), présentation du portfolio.
Remark:	Conditions d'admission: La connaissance et la mâitrise des langues française et allemande est requise Notes de cours: G. de Vecchi, L'enseignement scientifique, Delagrave, 2002, ISBN: 2-206-08471-6 H. Gudjons, Handlungsorientiert lehren und lernen, Klinkhardt, 2008, 2008, ISBN: 978-3-7815-1625-0 Kirchner Girwidz Häußler, Physikdidaktik, Springer, 2001, ISBN: 3-540-41936-5 H. Klippert, Methodentraining, Beltz 2005, ISBN: 3-407-62545-6 A.B. Arons Teaching Introductory Physics, Wiley, 1996, ISBN: 978-04711-37078 M. Reiss Understanding Science Lessons, Open University Press, 2001, ISBN: 978-0335-197699 H.K. Mikalsis (Hrsg.) Physik Didaktik, Cornelsen Scriptor, 2006, ISBN: 378-3589221486
Professor:	EICHER Carol, MALLINGER Marc

Computational Fluid Dynamics

Module:	Module 1.8 (Semester 1)
ECTS:	3
Language:	Anglais
Mandatory:	Non
Professor:	PETERS Bernhard, AMINNIA Navid

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Communicating science

Module: Module 1.8 (Semester 1)

ECTS: 3

Objective:
Learn to simplify without loss of accuracy when dealing with non-experts
Know your audience
Learn how to deal with nervousness
Learn how to explain things simply
Improvement of presentation skills (interactive, body language, pace)

Course learning outcomes:
Presentation skills
Organizational skills
Teaching skills
Outreach skills

Description: The course is a mix of theoretical introductions, practical experiences within the group and finally outreach activites in direct contact with the public (high school students, general public at events). All field work will be performed within the frame of the Scienteens Lab's workshops. This requires some flexibility regarding the personal schedule.

Teaching modality: Preparation and execution of field work (total: 24h of field work).

All field work will be performed within the frame of the Scienteens Lab's workshops and presence at events. Field work can be performed distributed over both semesters. This requires some flexibility regarding the personal schedule.

Language: Anglais

Mandatory: Non

Evaluation:
Active participation
Attendance
Written final project, report, presentation or movie

Remark: Support :

The course material is dynamically evolving within the group and part of the course process. Exemplary material will be provided and the participants can bring examples themselves.
Literature :
Pierre Laszlo: Communicating Science, A Practical Guide
Carmine Gallo: Talk Like TED
…and many more

Professor: REDINGER Alex

Academic English B2

Module: Module 1.8 (Semester 1)

ECTS: 3

Objective: **Remote teaching**

This course aims to develop your academic writing, speaking, reading and listening skills to a B2 CEFR (Common European Framework) level (upper intermediate).

This course is designed to reach the target level in 20 sessions spread over two semesters. You can take one semester only and get ECTS for that semester but you will not have reached a B2 level.

Course learning outcomes: By the end of the 20-week course, you should be able to do the following at B2 level:

- **Write**well-structured, coherent and cohesive essays and reports
- **Speak**to present your opinions in well-structured oral presentations, participate in academic discussions and debates
- **Understand**and critically evaluate academic texts and sources
- **Understand**lectures, presentations and academic discussions
- **Use**a wide range of academic vocabulary, grammatical structures and an appropriate academic register

Description: **Teaching mode: online**

You will develop your academic vocabulary and grammar while improving your reading, writing, listening and speaking skills within academic contexts such as essays, lectures, discussions and oral presentations.

This course is designed to reach the target level in 20 sessions spread over two semesters. You can take one semester only and get ECTS for that semester but you will not have reached a B2 level.

Teaching modality: Remote teaching

Language: Anglais

Mandatory: Non

Evaluation: Note that you must attend at least 7 out of 10sessions per semester and pass the course to be awarded credits.

Per semester, your grade is composed of the following:

- Assignments (50%): three written assignments and two oral assignments
- Final test (50%) of all the five units covered (reading, listening, grammar and vocabulary).

Remark: **Required Textbook**

Hewings, M. (2012). Cambridge Academic English, an integrated skills course for EAP. Upper Intermediate Student's Book + audio CD and DVD. Cambridge University Press. ISBN 978-0521165204

Professor: LINEHAN Jean

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Semester 2

Ferroelectrics and multiferroics

Module: Module 2.1 (Semester 2)

ECTS: 4

Objective: The lecture aims at

- introducing the student to the basic principles of ferroelectricity and related phenomena, including the simultaneous occurrence of (and interaction between) ferroelectricity and magnetism (magnetoelectric multiferroism),
- applying these principles to problems in fundamental and applied ferroelectricity and multiferroicity
- developing the ability to critically assess basic experimental and simulation results in the field

Course learning outcomes: After completion of the course, the student is expected to understand and explain
- the basic quantities and phenomenology of ferroelectricity and multiferroicity

- the basic theoretical and experimental approaches in the field

- the basic understanding of the main effects, at both atomistic and macroscopic levels

- the basics of model ferroelectric and magnetoelectric multiferroic materials

- the basics of the application of these materials in devices

- the current trends in the field

Description:

- **Basics of dielectrics and ferroelectrics**

- Electric polarization and dielectric response

- Basic ferroelectric phenomenology

- Ferroelectric materials, properties and applications

- **Ferroelectric phase transitions**

- Ferroelectricity, an example of structural phase transition

- Crystallographic and symmetry considerations

- Landau theory of ferroelectric phase transitions

- Soft phonon modes and response anomalies

- Strain-related effects, ferroelasticity

- Ferroelectric domains and domain walls

- Proper vs. improper ferroelectricity

- **Experimental characterization techniques**

- Dielectric and vibrational spectroscopies

- Diffraction methods for structural resolution

- Local-probe microscopies

- **Theoretical approaches to ferroelectric phenomena**

- Quantum mechanical first-principles simulations

- Atomistic effective potentials, force fields

- Continuum models, phase fields

- **Multiferroics (I)**

- Review of basic concepts in magnetism and magnetic materials

- Key magnetic and magnetostructural interactions

- **Multiferroics (II)**

- Type I multiferroics (strong ferroelectric and magnetic orders)

- Type II multiferroics (strong magnetic order, slave polar order)

- Artificial multiferroics

- **Ferroelectrics and multiferroics in practice**

- Applications of ferroelectrics

- Applications of multiferroics

- **Advanced topics**

- Photoferroelectrics

- Ferroelectric nanostructures, field effects and emerging properties

- Energy applications (harvesting, storage, cooling, etc.)

- Ferroelectric and multiferroic memories

Teaching modality: Lecture

Language: Anglais

Mandatory: Oui

Evaluation: Oral exam

Remark: Support :
Powerpoint presentation / blackboard

Literature :

M. E. Lines and A. M. Glass, Principles and Applications of Ferroelectrics and Related Materials

(Clarendon Press, Oxford, 1977).

K. M. Rabe, C. H. Ahn and J.-M. Triscone, Physics of Ferroelectrics - A Modern Perspective(Springer, 2007).

B. A. Strukov and A. P. Levanyuk, Ferroelectric Phenomena in Crystals(Springer, 1998).

C. Kittel, Introduction to Solid State Physics (8 thedition)(John Wiley & Sons, 2005).

N. W. Ashcroft and N. D. Mermin, Solid State Physics(Harcourt College Publishers, 1976)

S. Blundell, Magnetism in Condensed Matter(Oxford University Press, 2001).

A. Aharoni, Introduction to the Theory of Ferromagnetism(Oxford University Press, 2000).

Professor: GUENNOU Mael, INIGUEZ Jorge

Introduction to General Relativity

Module: Module 2.2 (Semester 2)

ECTS: 4

Objective:
understand the physical motivations for a relativistic theory of gravitation
understand the differential geometrical techniques
acquire familiarity with the main experimental tests of general relativity
acquire the capacity to follow recent developments

Course learning outcomes:
mathematical techniques of tensor calculus
mathematical techniques of differential geometry, in curved spaces
physical foundations of general relativity
general covariance and its use
physical properties of the Schwarzschild solution(s)

outlook to applications in astrophysics and gravitational waves

Description:
Historical introduction and physical motivation for relativistic gravitation
principle of equivalence and Eoetvoes experiment
rapid review of main results from special relativity (relativistic mechanics and electrodynamics)
introduction to differential geometry (Riemannian metric, covariant and contravariant tensors, c ovariant derivative, curvature and the Riemann tensor)
Principle of general covariance
Einstein's field equation of gravitation, and the cosmological constant the outer Schwarzschild solution and experimental tests (detailed description of all classical experimental tests, including gravitational red-shift, perihelion shift, gravitational bending of light, radar echo delay, GPS, ..., observable consequences of the cosmological constant)

if time permits: the inner Schwarzschild solution and compact stars (white dwarfs) gravitational waves

This course will be directed towards a physical understanding of general relativity and will focus on experimental tests. Formal developments will be kept to a necessary minimum.

Teaching modality: Cours magistral and TDs

Language: Anglais

Mandatory: Oui

Evaluation: final examination and active participation at the exercice classes

Remark: Books: S. Weinberg, Gravitation & Cosmology (Wiley)
L. Ryder, Introduction to General Relativity (Cambridge Univ. Press)
T.-P. Cheng, Relativity, Gravitation and Cosmology, 2e ed (Oxford Univ. Press)
A. Barrau, J. Grain, Relativite Generale (Dunod)
C.M. Wild, Confrontation between general relativity and experiments, Living Reviews Relativity, 17, 4 (2014)
C.M. Wild, Theory and Experiment in gravitational physics, 2e ed, (Cambridge Univ. Press)

Professor: HENKEL Malte

Classical and Quantum Transport

Module: Module 2.3 (Semester 2)

ECTS: 4

Objective: In this course, students will learn to understand and describe transport phenomena in physical classical. Transport phenomena (electric current, heat transport, motion of fluids) are uniquitous both in classical as well as in quantum physics. Starting from the important equations of classical transport theory (Boltzmann equation, Navier-Stokes equation) and the theory of open systems (Langevin and Fokker-Planck equations), we will move on to quantum systems, where we will mostly focus on electronic transport. The student should learn the basic techniques applicable to noninteracting systems (scattering theory) and interacting systems (Green's functions and master equations). Moreover, the students will learn to model nonequilibrium states in quantum systems (using for instance linear response theory or Keldysh technique).

Course learning outcomes: A student who takes this course will become familiar with the most important transport equations, which are ubiquitous in physics and engineering. He/she will understand how to derive them and how to solve them by applying them to simple situations.

Description: Transport phenomena (electric current, heat transport, motion of fluids) are ubiquitous both in classical as well as in quantum physics. Starting from the important equations of classical transport theory (Boltzmann equation) and the theory of open systems (Langevin and Fokker-Planck equations), we will move on to quantum systems, where we will mostly focus on electronic transport. Here, the student will learn the basic techniques applicable to noninteracting systems (scattering theory) and interacting systems (Green's functions and master equations). Moreover, the students will learn to model non-equilibrium states in quantum systems using for instance linear response theory or Keldysh technique.

Teaching modality: Lecture + TD

Language: Anglais

Mandatory: Oui

Evaluation: Written exam

Professor: SCHMIDT Thomas, WU Kunmin

Semiconductors and Solar Cells

Module: Module 2.4 (Semester 2)

ECTS: 4

Objective: This course aims at:
• giving a short overview/repetition on the electronic structure of semiconductors (bands and defects)
• introducing the students to charge carrier statistics
• educating the students on the optical properties of semiconductors
• training the students in basics of pn and Schottky junctions
• introducing the students to junctions under illumination and the functioning of solar cells
• introducing the students to the thermodynamic balances in solar cells

Course learning outcomes: A student who passes this course will be able to:
- understand the role of doping in semiconductors
- describe qualitatively and quantitatively absorption and light emission in semiconductors
- delineate qualitatively and quantitatively the behaviour of pn junctions in the dark and under illumination
- explain qualitatively and quantitatively the efficiency limits in solar cells
The course will enable the student to study the literature on current research topics in the field of semiconductor physics.

Description:
• Electronic structure of semiconductors
• Charge carrier statistics
• Excitation and recombination
• p/n junction in the dark and under illumination
• The equilibria in a solar cells
• Schottky contacts and transistors

Teaching modality: Lecture + TD

Language: Anglais

Mandatory: Oui

Evaluation: Intermediate written exam and final oral exam

Remark: Support :
Lecture Slides

Literature :
- R. F. Pierret, Advanced Semiconductor Fundamentals, Prentice Hall
- P. Yu and M. Cardona, Fundamentals of Semiconductors: Physics and Materials Properties, Springer
- K. Seeger, Semiconductor Physics, Springer
- S.M. Sze, K.K. Ng, Physics of Semiconductor Devices, Wiley
- P. Würfel, Physics of Solar Cells, Wiley
- M. Grundmann, The Physics of Semiconductors, Springer
- J. Pankove, Optical Processes in Semiconductors, Dover
- W. Mönch, Electronic Properties of Semiconductor Interfaces, Springer

Professor: SIEBENTRITT Susanne

Nonequilibrium soft and active matter

Module: Module 2.5 (Semester 2)

ECTS: 4

Objective: Students will be given an overview of the techniques required to model and analyze fluctuations for a large class of systems in soft and living matter. First, we will present the equivalence between Langevin equation, Fokker-Planck equation, and path probability to describe the time-evolution of a stochastic process. On this basis, we will establish the essential properties of equilibrium, including steady-state properties (Boltzmann distribution, equipartition theorem) and relaxation to steady state (linear response, fluctuation-dissipation theorem, Green-Kubo formulas). We will also discuss how the laws of thermodynamics extend to stochastic processes (stochastic thermodynamics, fluctuation theorems), with applications to colloidal engines. Then, we will introduce a specific class of nonequilibrium systems, which extract energy from their environment to sustain an individual directed motion, known as *active matter*. We will discuss the consequences of self-propulsion in specific examples. For many-body systems, we will show that it can lead to collective effects without any equilibrium equivalent, which will be rationalized based on coarse-grained hydrodynamic equations.

Course learning outcomes: Students will become familiar with techniques of statistical mechanics to analyze fluctuations beyond steady state, both for equilibrium and nonequilibrium systems, including recent progress in stochastic thermodynamics.

Description:
> Modeling fluctuations: Langevin equation, Fokker-Planck equation, path probability
> Symmetry of fluctuations: fluctuation-dissipation, linear response, fluctuation theorems
> Stochastic thermodynamics: energetics at microscopic scale, first and second laws, engines
> Active matter: particle-based approach, collective effects, consequences of irreversibility
> Field theories: coarse-graining microscopic dynamics, extended Landau-Ginzburg approach

Teaching modality: Lecture (30 hours) + Tutorials (15 hours)

Language: Anglais

Mandatory: Oui

Evaluation: Oral and/or written exam.

Remark: Relevant literature

Master of Science in Physics - Master of Science in Physics

- Van Kampen, 'Stochastic processes in physics and chemistry'
- Gardiner, 'Handbook of stochastic methods'
- Risken, 'The Fokker-Planck equation'
- Chaikin, Lubensky, 'Principles of condensed matter physics'
- Chandler, 'Introduction to modern statistical mechanics'.

Professor: FODOR Etienne

Lab class

Module: Module 2.6 (Semester 2)

ECTS: 6

Objective: The module aims at
• familiarizing the student with modern research topics in experimental and theoretical condensed-matter physics
• fostering the student's ability to autonomously achieve scientific tasks
• introducing the student to modern experimental techniques and challenging theoretical approaches
• strengthening the student's experimental and analytic skills
• developing the student's capability to interpret and properly describe scientific results

Course learning outcomes: A student who passes this course is expected to be able
• to tackle new scientific tasks in experimental and theoretical condensed-matter physics
• to familiarize himself with modern experimental tools and challenging theoretical approaches
• to work on a modern research topic with a proper autonomy
• to work out and defend scientific reports

Description: Examples for experiments include:
• Electrochemical and thin film properties of Copper (8 hours)
• Opto-electric properties of semiconductors in Schottky barriers (8 hours)
• Magnetometry (8 hours)
• X-ray diffraction (8 hours)
• Rare Event Sampling (8 hours)
• Free Energy Estimation (16 hours)
• Rheology (16 hours)
• Temperature modulated differential scanning calorimetry (16 hours)
• Solar cells (16 hours)
• Photoluminescence (8 hours)
• Raman IR (8 hours)
• TEM, SEM (8 hours)
• Band-structure calculations of semiconductors (16 hours)
• Electric currents in nanojunctions (16 hours)

Teaching modality: Practical training

Language: Anglais

Mandatory: Oui

Evaluation: Written reports on experiments; continuous control

Remark: Support :
Handouts describing topics and tasks and literature references indicated therein
Literature :
Handouts describing topics and tasks and literature references indicated therein

Professor: EHRE Florian

Literature Seminar

Module: Module 2.7 (Semester 2)

ECTS: 2

Objective: The course aims at introducing the student to basic topics of condensed-matter physics as well as teaching him/her to read scientific literature, and to present and defend its contents orally.

Course learning outcomes: A student who passes this course will be able to:
- read and understand the main ideas of a scientific article
- present and defend a piece of scientific research to an audience

Description: Examples for possible seminar presentations:
- Solution of the 1D Ising model
- Capillary waves at gas liquid interfaces
- Skyrmion lattices in metallic and semiconducting B20 transition metal compounds
- Dynamic nuclear polarization
- Graphene and other two-dimensional materials: physical properties and potential technological applications.
- Topological insulators: what are they, how do they work, and what is their technological relevance?

Teaching modality: Seminar

Language: Anglais

Mandatory: Oui

Evaluation: Oral presentation (seminar)

Remark: Support :
Scientific articles and references therein
Literature :
Scientific articles and references therein

Professor: BARRAGAN YANI Daniel Antonio

Partial Differential Equations II

Module: Module 2.8 (Semester 2)

ECTS: 8

Objective: Learning tools in order to deal with PDE, understanding the interplay between local and global problems and techniques.

Description: Distributions as generalized functions continued, Sobolev spaces, elliptic regularity, elliptic operators on compact manifolds, some non-linear equations.

Language: Anglais

Mandatory: Non

Evaluation: Written exam

Remark: Literatur

- Jost: Postmodern analysis
- Folland: Introduction to partial differential equations
- Reed-Simon: Methods of mathematical physics I-IV
- Aubin: Nonlinear analysis on manifolds

Professor: OLBRICH Martin

Principles of Software Development

Module: Module 2.8 (Semester 2)

ECTS: 5

Objective: The objective of the course is to introduce some principles of software development through the presentation of the Android ecosystem. After successful completion of this course the student should be able to:
- understand the main principles on which Java is based on;
- efficiently use software repositories or source code management systems and make the difference between git, svn or cvs

- understand the notion of design patterns
- implement an Android application and understand the concept of Inter-Component Communications.

Course learning outcomes: * design a reusable and evolvable software

* successfully conduct a software project

* leverage APIs

Description: Sessions on Java

Session on Design Pattern
Session on Software development lifecycle
Session on source code management systems
Session on Introduction to Android
Sessions on Android Interface and Communication (Layout, Android Activity and introduction to the concept of Intent)
Sessions on Android Data and Services (Services, Broadcast receiver, and Content Providers)

	Session for the preparation of the final project Sessions of practical
Teaching modality:	The lessons are combining (formal) presentations and practical exercises. Each student will write code! Bring your laptop.
Language:	Anglais
Mandatory:	Non
Evaluation:	A final written exam will account for 50% of the grade. The remaining 50% are based on a project evaluation focusing on the implementation of an Android Application.
Professor:	BISSYANDE Tegawendé François d Assise

Knowledge Discovery and Data Mining

Module:	Module 2.8 (Semester 2)
ECTS:	5
Objective:	We understand Data Mining (Knowledge Discovery) as a life-cylce process from data to information and insights. In times of Big data, Data Mining has become a central interest both for industry and academia. In this course, we discuss several data-related aspects like preprocessing or pricacy as well as selected aspects of Machine Learning. An expansive definition of Data Mining, which is the derivation of insights from masses of data by studying and understanding the structure of the constituent data, and selected applications complete the course.
Course learning outcomes:	* Explain the fundamental concepts of data mining and knowledge discovery * List the properties of data relevant for deriving interesting and useful information/observation from that. * Explain machine learning algorithms and strategies to deploy the discovered results * Argue the importance of domain knowledge during the data analysis with its scope and limitations
Description:	* Definition and Process. * Data Mining, Data Science, and the Big Data Hype. * Data Quality and Preprocessing * Data Privacy and Security. * Data and Information Visualization. * Machine Learning for Clustering, Classification, Association Discovery, Sequential Pattern Analysis, and/or Time Series Analysis.
Teaching modality:	The course is organised as a lecture with integrated exercises. It follows the "Information Retrieval" course and will itself be continued in Semester 3 by a more intensive discussion about "Machine Learning". Each participant must be inscribed via Moodle. Course material will be uploaded regularly.

Language: Anglais

Mandatory: Non

Evaluation: 60% oral or written examination; 40% midterm tests

Remark: **Selected references:**

* M. Berry, G. Linoff: Mastering Data Mining, John Wiley & Sons, 2000.
* U. Fayyad, G. Piatetsky-Shapiro, P. Smyth, R. Uthurusamy: Advances in Knowledge Discovery and Data Mining, AAAI/MIT Press, 1996.
* J. Han, M. Kamber: Data Mining: Concepts and Techniques, 2nd edition, Morgan Kaufmann, ISBN 1558609016, 2006.
* I. Witten, E. Frank, M. Hall: Data Mining: Practical Machine Learning Tools and Techniques, 3nd Edition, Morgan Kaufmann, 2011.

Professor: SCHOMMER Christoph

Didactics for Physics 2

Module: Module 2.8 (Semester 2)

ECTS: 3

Objective:

- découvrir la richesse de l'enseignement de la physique
- planifier et vivre des situations de TP en classe
- expérimenter différentes méthodes modernes d'enseignement
- analyser ses propres performances pour mieux s'orienter dans son choix professionnel
- évaluer la performance des élèves
- comprendre l'enseignement de la physique au secondaire et secondaire technique

Course learning outcomes: Connaître les multiples facettes de l'apprentissage et de l'enseignement de la physique et les défis posés à l'enseignant.

Teaching modality: cours magistraux, travail indépendant, travaux pratiques, travaux dirigés

Language: Français, Allemand

Mandatory: Non

Evaluation: Engagement régulier, élaboration d'un portfolio personnel (pièces créées à partir des éléments traités en cours), présentation du portfolio

Remark: Notes de cours
G. de Vecchi, L'enseignement scientifique, Delagrave, 2002, ISBN: 2-206-08471-6
H. Gudjons, Handlungsorientiert lehren und lernen, Klinkhardt, 2008, 2008, ISBN: 978-3-7815-1625-0
Kirchner Girwidz Häußler, Physikdidaktik, Springer, 2001, ISBN: 3-540-41936-5
H. Klippert, Methodentraining, Beltz 2005, ISBN: 3-407-62545-6
A.B. Arons Teaching Introductory Physics, Wiley, 1996, ISBN: 978-04711-37078
M. Reiss Understanding Science Lessons, Open University Press, 2001, ISBN: 978-0335-197699
H.K. Mikalsis (Hrsg.) Physik Didaktik, Cornelsen Scriptor, 2006, ISBN: 378-3589221486

Professor: EICHER Carol, MALLINGER Marc

Advanced engineering materials

Module: Module 2.8 (Semester 2)

ECTS: 4

Objective: Knowledge of structural materials (metals as ferrous and nonferrous alloys; ceramics and glasses;polymers, and composites) and their use in the view of a sustainable use of resources.

Course learning outcomes: The students will be capable to understand the different properties of the different key engineering materials and their use.

Description:

Metals:
· Ferrous alloys (carbon and low-alloy steels, high-alloy steels, cast irons) and recent developments in high-strength steel
· Nonferrous alloys (aluminium alloys, magnesium alloy, titanium alloys, and other alloys)
· Processing of metals and the influence on their properties
Ceramics and glasses:
· Crystalline ceramics
· Glasses
· Glass-ceramics
· Processing of ceramics and glasses and the influence on their properties
Polymers:
· Thermoplastic polymers
· Thermosetting polymers
· Processing of polymers
Composites:
· Fiber-reinforced composites
· Aggregate composites
· Honeycomb structures
· Properties on composites and the property averaging
· Processing of composites
Materials and our environment:
· Environmental aspects of design
· Recycling

Teaching modality: Lectures

Language: Anglais

Mandatory: Non

Evaluation: Written Examination

Professor: USELDINGER Ralph

Semester 3

Lab Class in Preparation for Master Thesis

Module: Module 3.1 (Semester 3)
ECTS: 27
Language: Anglais
Mandatory: Oui
Professor: MICHELS Andreas

Seminar on the Master Thesis Topic

Module: Module 3.1 (Semester 3)
ECTS: 3
Language: Anglais
Mandatory: Oui
Professor: MICHELS Andreas

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Semester 4

Master Thesis

Module: Module 4.1 (Semester 4)
ECTS: 20
Language: Anglais
Mandatory: Oui
Professor: LAGERWALL Jan, SCHMIDT Thomas

Defense of Master Project

Module: Module 4.1 (Semester 4)
ECTS: 10
Language: Anglais
Mandatory: Oui
Professor: LAGERWALL Jan, SIEBENTRITT Susanne