Course catalogue

Engineer Specializing in Physics

First year

Metz Campus of CentraleSupélec

last update: August 12, 2025

Semester 5

ISP-PHY-S05-14		Physics S05	7 ECTS
SPM-PHY-001	2	Quantum Physics 1	30.0 h
SPM-PHY-002	2	Statistical Physics	21.0 h
SPM-PHY-003	2	Advanced Electromagnetism	18.0 h
SPM-PHY-004	0	Experimental Physics	12.0 h

ISP-PHY-S05-17		Mathematics S05	5 ECTS
SPM-MAT-001	3	Mathematics for Engineers	36.0 h
SPM-MAT-002	2	Probability	24.0 h

ISP-PHY-S05-22		Engineering and Systems S05	3 ECTS
SPM-SIC-001	1.0	Signals and Systems	36.0 h

ISP-PHY-S05-25		Computing and Data Sciences S05	5 ECTS
SPM-INF-001	1	Free Softwares for Engineers	13.5 h
SPM-INF-002	2	Python for Scientists	21.0 h
SPM-INF-003	2	Introduction to C/C++ Programming	25.5 h

ISP-PHY-S05-27		Project and Research S05	3 ECTS
SPM-NCL-001	1	Introduction to Research 1	12.0 h
SPM-HEP-002	1	Scientific Dissemination Project 1	12.0 h
SPM-PRJ-007	1	Collaborative Scientific Project 1	15.5 h

ISP-PHY-S05-08		Humanities Management and Business Development S05	3 ECTS
SPM-HEP-001	1	Oral and written communication	15.0 h
SPM-HEP-003	1	Engineer, Environment and Society	12.0 h
SPM-HEP-008	1	Project Management	15.0 h
1SL9000	P/F	Sport S05	21.0 h

ISP-PHY-S05-02		Modern Languages S05	4 ECTS
LV1S05	1	Foreign Languages and Culture 1	21.0 h
LV2S05	1	Foreign Languages and Culture 2	21.0 h

Semester 6

ISP-PHY-S06-15		**Physics S06**	**5 ECTS**
SPM-PHY-009	2	Introduction to Condensed Matter Physics and Nanoscience	30.0 h
SPM-PHY-010	1	Seminar Series : Emergent Topics in Physics	12.0 h
SPM-PHY-011	2	Quantum Physics 2	24.0 h

ISP-PHY-S06-18		**Mathematics S06**	**4 ECTS**
SPM-MAT-003	1	Statistics	25.5 h
SPM-MAT-005	1	Numerical Methods for the Discretization of Physical Equations	24.0 h

ISP-PHY-S06-20		**Engineering Physics S06**	**4 ECTS**
SPM-PHY-005	*1*	*BioPhysics - Modeling and Measure for Biotechnologies*	*27.0 h*
SPM-PHY-008	*1*	*Physics of Complex Systems*	*24.0 h*
SPM-PHY-006	*1*	*Nonlinear Physics*	*24.0 h*
SPM-PHY-007	*1*	*Biophysics - Bioprocess Engineering*	*21.5 h*

ISP-PHY-S06-23		**Engineering and Systems S06**	**6 ECTS**
SPM-AUT-001	1	Systems and Models	36.0 h
SPM-ELE-001	1	Electronics	33.0 h

ISP-PHY-S06-28		**Project and Research S06**	**3 ECTS**
SPM-NCL-002	1	Introduction to Research 2	13.5 h
SPM-HEP-009	1	Scientific Dissemination Project 2	14.0 h
SPM-PRJ-008	1	Collaborative Scientific Project 2	15.5 h

ISP-PHY-S06-09		**Humanities Management and Business Development S06**	**4 ECTS**
SPM-HEP-005	1	Economic, Industrial and Financial Systems	18.0 h
SPM-HEP-006	1	Commons	12.0 h
SPM-HEP-023	1	Job Application Preparation	15.0 h
1SL9000	P/F	Sport S06	21.0 h
SPM-STA-001	P/F	Execution Internship	0.0 h

ISP-PHY-S06-03		**Modern Languages S06**	**4 ECTS**
LV1S06	1	Foreign Languages and Culture 1	21.0 h
LV2S06	1	Foreign Languages and Culture 2	21.0 h

Quantum Physics 1

Course supervisor: Damien Rontani

Total: 30.0 h **CM:** 16.5 h, **TD:** 12.0 h

SPM-PHY-001 *back*

Description: Quantum Physics 1, offered in the first-year common core curriculum, aims to introduce the fundamental concepts of wave physics as well as the modern mathematical formalism of quantum physics, notably the Schrödinger equation. Students will develop a solid understanding of essential quantum phenomena and learn to use the mathematical tools specific to quantum mechanics, including operator algebra and its properties. The course will be based on key experiments that laid the foundation of quantum theory (double-slit experiment, photoelectric effect, Stern-Gerlach experiment) to present the fundamental postulates of quantum mechanics and justify the transition from classical to quantum formalism. The notions of orbital angular momentum quantization and spin will be covered, along with their use in the study of two-level systems and a first description of the hydrogen atom. Finally, several practical applications will be examined to illustrate the relevance of these concepts, including the MASER, atomic clocks, and Nuclear Magnetic Resonance (NMR). This course provides an essential foundation for understanding quantum systems and prepares students for advanced courses in physics, photonics, nanotechnologies, or quantum engineering.

Bibliography:

- Ref. [1] : C. Cohen-Tannoudji, F. Laloë, B.Diu, Mecanique Quantique – Tome 1, EDP Science CNRS Edition (2018)
- Ref. [2] : J.-L. Basdevant, J. Dalibard, Mécanique Quantique, Ellipse Edition (2006)

Learning outcomes: At the end of this course, students will be able to: AA1: Understand and implement the fundamental postulates of quantum mechanics – AA2: Understand and apply the theory of angular momentum – AA3: Solve a wave physics problem by applying the Schrödinger equation – AA4: Apply the quantum formalism to simple quantum systems – AA5: Explain the foundational experiments of quantum mechanics

Evaluation methods: 1h30 written test, can be retaken.

Evaluated skills:

- Physical Modeling

Statistical Physics

Course supervisor: Nicolas Marsal

Total: 21.0 h **CM:** 15.0 h, **TD:** 4.5 h

SPM-PHY-002 *back*

Description: Statistical physics is one of the pillars of modern physics, alongside quantum mechanics and relativity. Its main objective is to study the collective behavior of systems composed of a large number of particles, aiming to establish a connection between macroscopic physical behavior and the microscopic laws that govern the evolution of individual components. By combining principles derived from (macroscopic) thermodynamics, we delve down to the microscopic scale to investigate how matter and energy are distributed.

Bibliography:

- Ref. [1] : C. Ngô and H. Ngô, Physique Statistique, Dunod, 3eme Ed. (2008)
- Ref. [2] : B. Diu, C. Guthmann, D. Lederer, B; Roulet, Physique Statistique, Hermann, (1997)

Learning outcomes: By the end of this course, students will be able to: AA1: Understand the fundamental concepts of statistical physics and thermodynamics – AA2: Use statistical distributions to describe the microscopic states of systems – AA3: Understand and analyze the different ensembles—canonical, grand canonical, and microcanonical—and their use in describing physical systems under various conditions – AA4: Compute distribution functions and partition functions to describe the statistical equilibrium of systems – AA5: Apply the concepts learned to solve concrete problems related to statistical physics

Evaluation methods: 1h30 written test, can be retaken.

Evaluated skills:

- Physical Modeling

Advanced Electromagnetism

Course supervisor: Delphine Wolfersberger, Nacera Bouldja

Total: 18.0 h **CM:** 12.0 h, **TD:** 6.0 h

SPM-PHY-003 *back*

Description: Electromagnetism is a basic discipline of physics present in many high-tech industrial sectors. This course will cover numerous applications in diverse fields such as telecommunications and photonics, thus demonstrating the diversity of devices where electromagnetism is involved. This course will provide a basic foundation of electromagnetism through various selected examples (e.g., propagation, guidance, modulation).

Learning outcomes: At the end of this course, students will be able to: AA1: Tackle and solve electromagnetism problems in free-space and guided-wave propagation based on Maxwell's equations. – AA2: Acquire fundamental notions of nonlinear optics formalism, enabling them to understand the operation of components that use nonlinear optical materials, such as modulators.

Evaluated skills:

- Physical Engineering Design
- Physical Modeling

Experimental Physics

Course supervisor: Damien Rontani, Nicolas Marsal

Total: 12.0 h **TP:** 12.0 h

SPM-PHY-004 *back*

Description: The Experimental Physics Labs (TrEx) are designed to illustrate key concepts in quantum physics, statistical physics, and advanced electromagnetism. Students will have the opportunity, among other things, to be introduced to the Scanning Tunneling Microscope (STM), an iconic instrument in atomic-scale microscopy. They will explore the operating principles of the STM, carry out experimental implementations, and analyze images obtained from crystalline surfaces. They will also study the Zeeman effect, a fundamental phenomenon in atomic physics corresponding to the splitting of spectral lines under the influence of a magnetic field. Through the observation and analysis of spectra, students will investigate the impact of an external magnetic field on atomic energy levels and deepen their understanding of atomic structure. In statistical physics, students will have the opportunity to numerically explore the Ising model—an emblematic model used to describe the collective behavior of spins in a magnetic system. In particular, they will aim to identify the phase transition between paramagnetic and ferromagnetic states. Finally, in electromagnetism, students will conduct an experiment involving information transmission through optical fiber, applying their knowledge of modulation and guided wave propagation.

Learning outcomes: At the end of this module, students will be able to: AA1: Put their theoretical knowledge into perspective through technological applications (e.g., quantum tunneling applied to microscopy) – AA2: Connect fundamental concepts of quantum mechanics to a concrete experimental application – AA3: Develop an initial critical approach to the analysis of scientific data – AA4: Numerically simulate interacting systems and compare analytical and numerical predictions.

Mathematics for Engineers

Course supervisor: Michel Barret

Total: 36.0 h **CM:** 18.0 h, **TD:** 15.0 h

SPM-MAT-001 *back*

Description: In this course, students are expected to acquire and master the formalisms, concepts, and mathematical results used in modeling physical systems or phenomena and engineering sciences. This particularly includes an advanced level in linear algebra and a thorough understanding of measure theory, Lebesgue integration, Fourier transform, and differential calculus.

Learning outcomes: By the end of this course, students will master the formalisms, concepts, and mathematical results used in modeling physical systems or phenomena and engineering sciences. They will have an advanced level in linear algebra and a thorough knowledge of measure theory, Lebesgue integration, Fourier transform, and differential calculus.

Evaluation methods: 3h written test, can be retaken.

Probability

Course supervisor: Michel Barret

Total: 24.0 h **CM:** 12.0 h, **TD:** 10.5 h

SPM-MAT-002 *back*

Description: By the end of the core curriculum course in probability, students will have mastered the concepts of random experiments, probability spaces, probability distributions, random variables (RVs), conditioning, and independence of RVs. They will be able to construct an appropriate probability space for a given random experiment (and vice versa), compute and use moments of real or complex RVs, recognize and utilize the Hilbert space structure of second-order complex RVs, and identify and apply various representations of probability distributions (cumulative distribution function, probability density function, characteristic functions, etc.). They will be able to recognize and apply common probability distribution models (Bernoulli, binomial, Poisson, Gaussian, etc.), as well as understand and use the different modes of convergence for sequences of random variables. Finally, they will be able to justify and apply the fundamental theorems of probability theory (Central Limit Theorem, Law of Large Numbers, etc.), and understand and use the concept of conditional expectation.

Learning outcomes: By the end of this course, students will be able to: use the concepts of random experiments, probability spaces, probability distributions, random variables (RVs), conditioning, and independence of RVs; construct an appropriate probability space for a given random experiment and vice versa; compute and use moments of real or complex RVs; recognize and utilize the Hilbert space structure of second-order complex RVs; identify and apply different representations of probability distributions (cumulative distribution function, probability density function, characteristic functions, etc.); identify common probability distribution models (Bernoulli, binomial, Poisson, Gaussian, etc.); recognize and use the different types of convergence for sequences of RVs; justify and apply the fundamental theorems of probability theory (Central Limit Theorem, Law of Large Numbers, etc.); and understand and apply the concept of conditional expectation.

Evaluation methods: 1h30 written test, can be retaken.

Signals and Systems

Course supervisor: Stéphane Rossignol

Total: 36.0 h **CM:** 18.0 h, **TD:** 6.0 h, **TP:** 12.0 h

SPM-SIC-001 *back*

Description: The digital world generates large volumes of diverse data (audio, images, video, physical measurements) associated with human activities in fields as varied as healthcare, telecommunications, industry, and the environment. Extracting meaningful information from these signals is increasingly essential for: decision-making (e.g., medical diagnosis), information encoding (e.g., data compression), analysis of physical phenomena (e.g., detection of mechanical faults), and signal restoration (e.g., removing noise from an audio signal). The course will begin by introducing fundamental concepts of signals (in particular, regarding distributions) and linear time-invariant systems (convolution, etc.). It will then address energy-related aspects (correlations, signal-to-noise ratio). This will lead to the study of the Fourier transform for analog signals and the spectral representations used in analog systems (e.g., for filtering). The course will then explore what happens when signals are discretized and digital systems are considered (Shannon, Gabor; discrete-time Fourier transform; Fast Fourier Transform). Finally, it will examine the reverse transition—from digital back to analog—as well as sampling rate conversion.

Bibliography:

- Ref. [1] : A.V. Oppenheim and R.W. Schafer, Discrete Time Signal Processing, Prentice Hall, 3rd Ed. (2009)

Learning outcomes: By the end of this first-year course, students will be able to understand and apply signal processing methods to solve various problems in information science, such as information transmission, signal denoising, physical parameter estimation, and spectral analysis. These problems arise in a wide range of applications, including automatic speech recognition, music recording identification, radar source localization, climate data analysis, medical image reconstruction in MRI, gravitational wave detection in astrophysics, and the development of next-generation cellular networks (5G, IoT).

Evaluation methods: Lab reports

Free Softwares for Engineers

Course supervisor: Jérémy Fix

Total: 13.5 h **CM:** 1.5 h, **TP:** 12.0 h

SPM-INF-001 *back*

Description: This course introduces the main tools of the free software world useful to an engineer. It covers the use of bash to interact with the system, the philosophy behind GNU tools and how to combine them (pipelines, IO redirection, etc.). We'll also take a look at how to combine various tools (git, python, awk, sed, lynx, ffmpeg, make), using them to carry out two projects. Assessment will be based on the practical reports.

Learning outcomes: At the end of this course, students will be able to interact with a Linux computer, invoking and articulating free software tools via a bash-like command interpreter.

Evaluation methods: Labwork report

External resources:

- Site du cours

Python for Scientists

Course supervisor: Jérémy Fix

Total: 21.0 h **CM:** 3.0 h, **TP:** 18.0 h

SPM-INF-002 *back*

Description: The aim of this teaching unit is to train students in the tools of the Python ecosystem for scientists. It covers the use of specialized libraries for a number of major themes: scientific computing with Numpy, signal processing with Scipy, managing and processing large volumes of data with pandas, formatting results with matplotlib and an introduction to machine learning with scikit-learn.

Learning outcomes: At the end of this course, students will be able to mobilize the tools of the Python ecosystem for the experimental parts of their scientific activities.

Evaluation methods: Practical reports

Evaluated skills:

- Physical Modeling

External resources:

- Site du cours

Introduction to C/C++ Programming

Course supervisor: Hervé Frezza-Buet

Total: 25.5 h **CM:** 10.5 h, **TD:** 3.0 h, **TP:** 12.0 h

SPM-INF-003 *back*

Description: This course covers C programming, focusing on execution threading (loops, function calls, recursive functions), memory manipulation (structured types, pointers, stack and heap, binary representations). The first steps towards object-oriented design (encapsulation without the syntax of an object language like C++). This course also covers the aspecst of separate compilation (headers, external variables, linkage, dynamic libraries, etc.).

Learning outcomes: On completion of this course, students will be able to write, compile and debug C/C++ programs involving the basic elements of the language.

Evaluation methods: Assessment based on participation in experiments and results.

External resources:

- C++ web pages

Introduction to Research 1

Course supervisor: Nicolas Marsal

Total: 12.0 h — **CM:** 6.0 h, **TD:** 4.5 h, **TP:** 1.5 h

SPM-NCL-001 *back*

Description: The Research Initiation course provides participants with both a practical and theoretical introduction to the fundamental principles of academic research. By exploring the various stages of the research process—from formulating a research question to communicating results—students will acquire essential skills to conduct effective research projects. Through hands-on exercises, case studies, and classroom discussions, participants will become familiar with methods for data collection and analysis, as well as with ethical standards and best research practices. This module provides a solid foundation for those wishing to pursue graduate studies or engage in independent research projects.

Learning outcomes: The learning outcomes of this module include the ability to formulate relevant research questions, design appropriate research methodologies, collect and analyze data rigorously, and interpret and communicate results clearly and coherently. Students will also learn to critically evaluate existing literature, adhere to ethical research standards, and work collaboratively.

Evaluation methods: Specific evaluation method defined by the various instructors

Evaluated skills:

- Research / Innovation
- Business Intelligence

Scientific Dissemination Project 1

Course supervisor: Hervé Frezza-Buet, Virginie Galtier

Total: 12.0 h **Projet:** 12.0 h

SPM-HEP-002 *back*

Description: Training in oral communication and pedagogy through preparation and practical implementation. Students design an educational activity for elementary school pupils on a scientific or technological topic (coding, physics, math, etc.). They will create the teaching materials and deliver the lesson in CM1 or CM2 classes (4th or 5th grade), under the supervision of the classroom teacher. The project may involve the FabLab. In semester 5, students define the content of their lesson, select pedagogical tools, and are assessed based on a detailed lesson plan (including content, required materials, and expected outcomes). This activity is part of the EntreElèvesinitiative, in collaboration with the Cité Éducative Metz-Borny.

Learning outcomes: At the end of this course, students will have had the experience of having to construct a communication adapted to an audience very different from their own, having made pedagogical choices to successfully get the message across. They will also have had the demanding experience of a real-life communication situation, which implies a certain degree of charisma.

Evaluation methods: Report describing the planned classroom intervention

Evaluated skills:

- Management
- Business Intelligence

Collaborative Scientific Project 1

Course supervisor: Damien Rontani

Total: 15.5 h **Projet:** 15.5 h

SPM-PRJ-007 *back*

Description: The project topic is part of the specialization in Physical Engineering. It is carried out over two semesters, S05 and S06, as a two-phase collaborative effort. It may be proposed by the teaching team, an industrial or academic partner, or chosen by the students themselves as a personalized subject. The Collaborative Scientific Project (PSC) builds on the skills developed in the Research Initiation course, also followed during semesters S05 and S06. It is structured as follows: During S05, students focus on a detailed literature review, aimed at establishing the scientific and technical background of the project, identifying current challenges in the field, and formulating a clear and well-founded research question. During S06, the project continues with the experimental, numerical, or theoretical implementation of the proposed solutions, the critical analysis of the obtained results, and the dissemination of the work in two formats: (i) a scientific oral presentation, intended for an academic audience; (ii) a public outreach deliverable in digital format (e.g., video, scientific animation, blog article), aimed at a general audience and designed to present the purpose and outcomes of the PSC in just a few minutes.

Learning outcomes: At the end of the project, students will be able to: AA1: Search, analyze, and synthesize scientific information from the state of the art – AA2: Define a research question and design an appropriate problem-solving approach. – AA3: Carry out a scientific investigation (experimental, numerical, or theoretical). – AA4: Critically interpret the results obtained. – AA5: Communicate the project outcomes effectively, both in writing and orally, to scientific and non-specialist audiences. – AA6: Collaborate effectively within a project team, demonstrating autonomy, organization, and a sense of responsibility.

Evaluation methods: Project report, deliverables (e.g., source code, experimental prototype, multimedia files), and oral presentation

Evaluated skills:

- Physical Engineering Design
- Physical Modeling
- Data Processing
- Management
- Business Intelligence

Oral and written communication

Course supervisor: Hervé Frezza-Buet, Damien Rontani

Total: 15.0 h **CM:** 4.0 h, **TP:** 11.0 h

SPM-HEP-001 *back*

Description: This course provides essential tools for effective oral and written communication in academic and professional contexts. On the oral side, students will learn how to speak in public, lead meetings and conduct interviews, manage their speaking time, and adapt to videoconferencing situations. On the written side, they will practice drafting various types of documents (technical or scientific reports, meeting minutes, specifications, responses to calls for projects, etc.), focusing on clear structure and content, while using appropriate tools for formatting and presentation.

Learning outcomes: By the end of this course, students will be able to communicate clearly, effectively, and professionally in a variety of situations, both in writing and orally.

Evaluation methods: Assessment based on participation in tutorials/labs and submitted results (including a pitch video recorded in a single take)

Evaluated skills:

- Management

Engineer, Environment and Society

Course supervisor: Julien Colin

Total: 12.0 h **CM:** 6.0 h, **TD:** 2.0 h, **TP:** 4.0 h

SPM-HEP-003 *back*

Description: This course aims at providing students with fundamental knowledge of the life cycles of resources (energy and non-energy: production/extraction, consumption, end-of-life) and their impact on climate and biodiversity, in relation to the demographic and geopolitical challenges of the 21st century.

Learning outcomes: At the end of this course, students will be familiar with the global challenges facing humanity and its environment in the 21st century, and will have an overview of their levers as citizens and engineers.

Evaluation methods: evaluation of involvement (mandatory and controlled attendance) and of a step back note.

Project Management

Course supervisor: Hervé Frezza-Buet, Damien Rontani

Total: 15.0 h **CM:** 12.0 h

SPM-HEP-008 *back*

Description: This course is designed to make students more effective in managing their projects by providing methodological frameworks and practical tools. They will learn to plan, organize, monitor, and lead a project and a team in various contexts. This course is complemented by the ”Management” course, which focuses more specifically on the human aspects of managing individuals and groups.

Learning outcomes: By the end of this course, students will have mastered the fundamentals of project management tools and methods, enabling them to effectively lead all phases of a collaborative project.

Evaluation methods: Case study

Evaluated skills:

- Management

Sport S05

Course supervisor: Hervé Frezza-Buet

Total: 21.0 h **TD:** 21.0 h

1SL9000 *back*

Description: Beyond the development of motor skills (physical, technical, and tactical), physical education courses aim to help students develop personal skills related to self-awareness and self-control, as well as interpersonal skills such as teamwork, active listening, communication, and group facilitation.

Foreign Languages and Culture 1

Course supervisor: Elisabeth Leuba

Total: 21.0 h **TD:** 21.0 h

LV1S05 *back*

Description: The first foreign language is generally English. Students are divided into level groups ; in class, work is not only focused on the 4 language competences but also on various topics studied in depth according to students' levels. Topics cover a range of fields, such as civilisation, society and the professional world. Limited class size enables active participation and significant improvement in the language. The educational approach is varied: group work, class presentations, specific exercises, research, debates, etc.

Learning outcomes: At the end of the course, students will have improved their ability to communicate in an international professional, academic or personal context.

Evaluation methods: Assessment will be by continuous assessment according to criteria to be determined by each teacher, taking into account personal investment in the course. Each course will be marked out of 20 at the end of the semester.

Evaluated skills:

- Management

Foreign Languages and Culture 2

Course supervisor: Beate Mansanti

Total: 21.0 h **TD:** 21.0 h

LV2S05 *back*

Description: Students are offered a range of second foreign languages at different levels, including for beginners. Students are divided into level groups; in class, work is not only focused on the 4 language competences but also on various topics studied in depth according to students' levels. Topics cover a range of fields, such as civilisation, society and the professional world. Limited class size enables active participation and significant improvement in the language. The educational approach is varied: group work, class presentations, specific exercises, research, debates, etc.

Learning outcomes: At the end of the course, students will have improved their ability to communicate in an international professional, academic or personal context.

Evaluation methods: Assessment will be by continuous assessment according to criteria to be determined by each teacher, taking into account personal investment in the course. Each course will be marked out of 20 at the end of the semester.

Evaluated skills:

- Management

Introduction to Condensed Matter Physics and Nanoscience

Course supervisor: Nicolas Marsal

Total: 30.0 h **CM:** 19.5 h, **TD:** 6.0 h, **TP:** 3.0 h

SPM-PHY-009 *back*

Description: Condensed matter physics explores the characteristics of dense matter, including materials in solid or liquid states, as well as materials that exist between these two states, such as liquid crystals. This branch of physics is extremely diverse in terms of phenomena studied and is one of the most dynamic research fields today. This course aims to train students to understand and characterize the physical properties of condensed matter at different scales (macro and micro). The teachings will cover a wide range of topics, from crystallography to solid-state physics and semiconductor components.

Bibliography:

- Ref. [1] : C. Kittel, Introduction to Solid State Physics. Wiley & Sons, 8th Ed. (2004)

Learning outcomes: By the end of this course, students will be able to: AA1: Understand and perform calculations in crystalline and amorphous structures – AA2: Analyze states of matter (solid, liquid, gas) and their thermodynamic properties – AA3: Understand electronic properties such as electronic band structures and electrical conductivity – AA4: Identify semiconductors, insulators, and metals based on their properties – AA5: Solve practical problems related to condensed matters

Evaluation methods: 1h30 written test, can be retaken.

Evaluated skills:

- Physical Modeling

Seminar Series : Emergent Topics in Physics

Course supervisor: Damien Rontani

Total: 12.0 h **TD:** 12.0 h

SPM-PHY-010 *back*

Description: The "Emerging Fields of Physics" course will consist primarily of seminars given by speakers from the academic world, coming from top universities and research centers in France and Europe. These seminars are a key component of the research training within the Engineering Physics program.

Evaluation methods: Assessment of participation (attendance is mandatory and monitored). Writing of a summary report.

Evaluated skills:

- Research / Innovation

Quantum Physics 2

Course supervisor: Nicolas Javahiraly

Total: 24.0 h **CM:** 15.0 h, **TD:** 7.5 h

SPM-PHY-011 *back*

Description: The Quantum Physics 2 course, offered in the first-year common core curriculum, builds on Quantum Physics 1 by introducing advanced concepts of quantum mechanics while reinforcing the previously acquired formalism. The course begins with the study of symmetries in quantum mechanics and their connection to conservation laws, providing a structured framework for analyzing quantum systems. It then introduces both time-independent and time-dependent perturbation methods, which are essential for tackling systems that cannot be solved exactly, with applications such as energy level corrections and field-induced transitions. The composition of angular momenta is then addressed, particularly spin addition, along with an introduction to Clebsch-Gordan coefficients—crucial for understanding atomic fine structure and spin-orbit coupling. Finally, the course covers indistinguishable particles, focusing on fermions, with the introduction of antisymmetric wavefunctions, the Pauli exclusion principle, and multi-electron atoms, laying the groundwork for understanding electronic structure. This course equips students with the tools needed to analyze complex quantum systems and prepares them for advanced topics in atomic physics, condensed matter, and quantum engineering.

Bibliography:

- Ref. [1] : C. Cohen-Tannoudji, F. Laloë, B.Diu, Mecanique Quantique – Tome 1, EDP Science CNRS Edition (2018)
- Ref. [2] : J.-L. Basdevant, J. Dalibard, Mécanique Quantique, Ellipse Edition (2006)
- Ref. [3] : M. Joffre, Physique Quantique Avancée. Cours de lEcole Polytechnique (2023)

Learning outcomes: At the end of this course, students will be able to: AA1: Identify situations where time-independent and time-dependent perturbation theory applies, and use it to construct approximate solutions – AA2: Apply the theory of angular momentum composition and understand atomic fine structure – AA3: Master the formalism associated with symmetries in quantum mechanics – AA4: Use the formalism of indistinguishable particles to analyze the structure of atoms with multiple electronic layers

Evaluation methods: 1h30 written test, can be retaken.

Evaluated skills:

- Physical Modeling

Statistics

Course supervisor: Michel Barret, Joël Legrand

Total: 25.5 h **CM:** 12.0 h, **TD:** 12.0 h

SPM-MAT-003 *back*

Description: In this course, students will acquire the mathematical, methodological, and computational foundations necessary to perform inference on the underlying probability distribution from observations of a random phenomenon (the data). This will enable them to analyze past phenomena or make forecasts for future events of a similar nature. To achieve this, students will learn the basic formalisms, concepts, and results of mathematical statistics. This includes, in particular, the definition of statistical models, the principles of estimation theory (maximum likelihood estimator, Bayesian estimator, etc.), and hypothesis testing theory (Neyman-Pearson test, chi-squared test, Kolmogorov-Smirnov test, etc.).

Learning outcomes: By the end of this course, students will have acquired a comprehensive set of mathematical, methodological, and computational skills essential for conducting in-depth statistical analyses based on observations of random phenomena (data). They will be able to draw inferences about the underlying probability distribution, enabling them to analyze past events and make forecasts about future events of a similar nature. Participants will have developed a solid understanding of the foundations of mathematical statistics, including the creation and definition of statistical models. They will be familiar with the core principles of estimation theory, using techniques such as the maximum likelihood estimator and the Bayesian estimator. In addition, they will be proficient in applying the principles of hypothesis testing theory, including methods such as the Neyman-Pearson test, the chi-squared test, and the Kolmogorov-Smirnov test. In summary, this course will equip students with the necessary skills to interpret and statistically analyze data, formulate reliable estimates, and carry out rigorous hypothesis tests. These competencies will be essential for making informed decisions based on empirical observations and for contributing meaningfully to problem-solving across a wide range of fields.

Evaluation methods: 1h30 written test, can be retaken.

Evaluated skills:

- Data Processing

Numerical Methods for the Discretization of Physical Equations

Course supervisor: Mehdi Adrien Ayouz

Total: 24.0 h **CM:** 10.5 h, **TD:** 4.5 h, **TP:** 9.0 h

SPM-MAT-005 *back*

Description: This course introduces the mathematical and algorithmic concepts for the discretization of ordinary differential equations (ODEs) and partial differential equations (PDEs) arising in the modeling of linear and nonlinear problems. For ODEs, the focus will be on Runge-Kutta methods with fixed and variable step sizes, as well as multi-step methods. For PDEs, emphasis will be placed on the finite difference method to approximate partial differential equations commonly encountered in physics, particularly parabolic and hyperbolic types. For this latter category, the course will cover explicit and implicit schemes, as well as the notions of consistency, stability, and convergence of numerical schemes. A significant practical component will allow students to implement and apply the numerical methods presented in lectures on computers for the analysis of physical phenomena or systems.

Bibliography:

- Ref. [1] : R. H. Landau, M. J. Páez, C. C. Bordeianu, Computational Physics: Problem Solving with Python, Wiley-VCH, 3rd Ed, 2015
- Ref. [2] : K. W. Morton, D. F. Mayers, Numerical Solution of Partial Differential Equations. An Introduction, Cambridge University Press, 2012

Learning outcomes: At the end of this course, students will be able to: AA1: Numerically simulate (using Matlab/Python) an ordinary differential equation (ODE) or a partial differential equation (PDE) using appropriate algorithms. – AA2: Analyze the stability properties of numerical schemes for simulating ODEs and PDEs. – AA3: Select the appropriate numerical simulation scheme based on the physical problem to be solved.

Evaluation methods: Labwork report

Evaluated skills:

- Physical Modeling

BioPhysics - Modeling and Measure for Biotechnologies

Course supervisor: Ninel Kokanyan, Cédric Guerin

Total: 27.0 h (optional) **CM:** 15.0 h, **TD:** 7.5 h, **TP:** 3.0 h

SPM-PHY-005 *back*

Description: Biotechnologies play a strategic role in many industrial sectors, including agri-food, pharmaceuticals, and environmental applications. Optimizing bioprocesses in these areas requires precise monitoring of critical parameters. Conventional approaches, which rely on offline analyses, are often time-consuming, costly, and can introduce contamination risks. In contrast, in situ measurement techniques—especially optical methods—enable real-time, non-invasive monitoring and generate large volumes of data that require advanced processing tools. This course introduces the fundamentals of industrial biotechnologies, the principles of physical measurement, and modeling approaches applied to biological systems. Particular attention is given to in situ optical techniques such as Raman spectroscopy. The course also covers data analysis using multivariate methods and neuro-inspired approaches.

Learning outcomes: At the end of this elective course, students will be able to: AA1: Experiment on a real bioprocess and collect in situ data – AA2: Process and analyze data using multivariate methods – AA3: Model and validate a predictive model of the biotechnological system – AA4: Interpret discrepancies between the model and experimental results.

Evaluation methods: 1h30 written test, can be retaken

Evaluated skills:

- Physical Modeling
- Data Processing

Physics of Complex Systems

Course supervisor: Damien Rontani

Total: 24.0 h (optional) **CM:** 12.0 h, **TD:** 6.0 h, **TP:** 6.0 h

SPM-PHY-008 *back*

Description: The physics of complex systems explores emergent behaviors and collective properties arising from the interaction of a large number of dynamical systems, agents, or components. This course offers an in-depth introduction to the field, with a focus on theory and dynamics, emergent phenomena, synchronization concepts, epidemic processes on networks, and the exploitation of network behavior for analog computing and machine learning.

Bibliography:

- Ref. [1] : A.-L. Barabasi, Network Science, Cambridge University Press (2016)
- Ref. [2] : P. Fieguth, An Introduction to Complex Systems, Springer, 2nd Ed. (2020)

Learning outcomes: By the end of the course, students will be able to: AA1: Define, explain, and identify application cases of the main concepts in the physics of complex systems – AA2: Analyze critical phenomena such as phase transitions – AA3: Model and analyze interacting systems in various fields using network physics and numerical simulation – AA4: Model, analyze, and simulate synchronization phenomena and epidemic processes – AA5: Leverage collective dynamics for analog computing and physical machine learning

Evaluation methods: Mini project

Evaluated skills:

- Physical Modeling
- Data Processing

Nonlinear Physics

Course supervisor: Marc Sciamanna

Total: 24.0 h (optional) **CM:** 15.0 h, **TD:** 9.0 h

SPM-PHY-006 *back*

Description: Physical systems in general are called dynamic because the state variables that characterize the state of these systems evolve in time and space when the parameters influencing these systems vary. When the dynamic relationships that link the state variables are non-linear functions of the state variables, the physical system is called a non-linear system. The non-linearity of these systems is at the origin of a great richness of their dynamic behaviors and allows the observation of new phenomena that interest scientists and engineers. Examples of non-linear dynamic systems include neural networks, electronic and optical oscillators, the dynamics of data propagation in a telecommunications network or the propagation of a virus. The most spectacular nonlinear dynamics are chaos - or the dynamics of a system that over time or while propagating presents an unpredictable evolution of its state variables - but also synchronization which allows two or more coupled nonlinear dynamic systems to reproduce the same dynamics, even chaotic. How the dynamics of a nonlinear system becomes complex and chaotic, and how this dynamic propagates between coupled oscillators in networks, are all fundamental questions but which also shed light on important fields of science and engineering such as neuroscience, artificial intelligence, telecommunications, epidemiology, quantum systems, etc. This course will therefore give the student the basic elements of what is more generally called nonlinear physics. It will be illustrated by numerous concrete cases taken from research work with an applied aim, which will allow the student to understand and implement the analytical and numerical techniques necessary for solving simple problems.

Bibliography:

- Ref. [1] : S. Strogatz, Nonlinear dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering, CRC Press (2014)

Learning outcomes: By the end of this course, students will be able to: AA1: Understand the scientific and multidisciplinary challenges of nonlinear science and network theory – AA2: Identify situations where the formalism of nonlinear physics can be applied – AA3: Know and apply techniques for analyzing nonlinear dynamical systems and networks of oscillators – AA4: Perform numerical simulations of nonlinear dynamical systems and dynamic networks

Evaluation methods: Mini project

Evaluated skills:

- Physical Modeling

Biophysics - Bioprocess Engineering

Course supervisor: Ninel Kokanyan, Cédric Guerin

Total: 21.5 h (optional) **TP:** 21.0 h

SPM-PHY-007 *back*

Description: This course takes place at the Biotechnology Chair of CentraleSupélec, located on the CentraleSupélec research campus in Pomacle. It aims to apply the knowledge acquired in the associated elective course on biophysics and biotechnologies in a real-world environment. Students will work on the in situ monitoring of a bioreactor under experimental conditions. Using advanced optical techniques and data processing tools, they will be required to build a predictive model of the observed bioprocess. Students will be organized into groups and supervised to carry out a complete engineering approach: observation, measurement, data processing, modeling, and presentation of results.

Learning outcomes: At the end of this elective course, students will be able to: AA1: Experiment on a real bioprocess and collect in situ data. – AA2: Process and analyze data using multivariate methods. – AA3: Model and validate a predictive model of the biotechnological system. – AA4: Interpret discrepancies between the model and experimental results.

Evaluation methods: 30 min mini-project defense

Evaluated skills:

- Physical Modeling
- Data Processing

Systems and Models

Course supervisor: Damien Rontani, Jean-Luc Collette

Total: 36.0 h **CM:** 18.0 h, **TD:** 6.0 h, **TP:** 12.0 h

SPM-AUT-001 *back*

Description: The Systems and Modeling course, part of the first-year core curriculum, aims to equip students with the necessary skills to accurately and effectively represent various types of systems using mathematical models. This facilitates the understanding, analysis, and optimization of systems in diverse contexts. The state-space representation—generally nonlinear—provides a highly generic modeling framework, particularly well-suited for numerical simulations of system behavior. However, a linearization step is often required afterward, in order to leverage the extensive set of analytical tools available for linear systems. These tools enable the resolution of differential equations, the assessment of system stability, and the analysis of closed-loop systems. In this context, the connection between time-domain and frequency-domain responses is well established, allowing for controller design via frequency-based methods that meet specific time-response specifications for a controlled system.

Learning outcomes: At the end of this first-year course, the student will be able to develop the mathematical model of a system in order to predict its behavior. They will also have acquired the methods required to perform numerical simulations based on this model. Finally, they will master the design of controllers used in feedback control problems.

Evaluation methods: Labwork evaluation.

Evaluated skills:

- Physical Modeling
- Data Processing
- Systems Analysis

Electronics

Course supervisor: Yves Houzelle, Nacera Bouldja

Total: 33.0 h **CM:** 12.0 h, **TD:** 7.5 h, **TP:** 10.5 h

SPM-ELE-001 *back*

Description: The first-year core Electronics course aims to provide the foundational knowledge required to design interfaces with the physical world. Integrated electronic components offer functions that can be used to build more complex systems capable of meeting specific needs. Moreover, there are more advanced integrated components that make use of basic components; these complex components can be configured or programmed, allowing for simpler and faster implementation of the final system.

Bibliography:

- Ref. [1] : A. Agarwal, J.H. Lang, Foundations of analog and digital electronic circuits, Morgan Kaufmann Publishers, 1st Ed. (2005)
- Ref. [2] : D. M. Harris, S. L. Harris, Digital Design and Computer Architecture, Morgan Kaufmann Publishers, 2nd Ed. (2012)
- Ref. [3] : J. Oksman, J.-P. Zsylowicz, P. Benabes, G. Seignier, Y. Houzelle, Systèmes logiques et électronique associée, Volumes 1 et 2, CentraleSupélec, (2020)

Learning outcomes: By the end of the course, students will be able to: – AA1: Specify an analog signal processing chain – AA2: Simulate and test a simple circuit – AA3: Implement a simple application using a microcontroller or a programmable logic circuit

Evaluation methods: 3h written test, can be retaken

Evaluated skills:

- Physical Modeling
- Systems Analysis

Introduction to Research 2

Course supervisor: Nicolas Marsal

Total: 13.5 h **CM:** 6.0 h, **TD:** 6.0 h, **TP:** 1.5 h

SPM-NCL-002 *back*

Description: The Research Initiation course provides participants with both a practical and theoretical introduction to the fundamental principles of academic research. By exploring the various stages of the research process—from formulating a research question to communicating results—students will acquire essential skills to conduct effective research projects. Through hands-on exercises, case studies, and classroom discussions, participants will become familiar with methods for data collection and analysis, as well as with ethical standards and best research practices. This module provides a solid foundation for those wishing to pursue graduate studies or engage in independent research projects.

Learning outcomes: The learning outcomes of this module include the ability to formulate relevant research questions, design appropriate research methodologies, collect and analyze data rigorously, and interpret and communicate results clearly and coherently. Students will also learn to critically evaluate existing literature, adhere to ethical research standards, and work collaboratively.

Evaluation methods: Specific evaluation method defined by the various instructors

Evaluated skills:

- Research / Innovation
- Business Intelligence

Scientific Dissemination Project 2

Course supervisor: Hervé Frezza-Buet, Virginie Galtier

Total: 14.0 h **Projet:** 12.0 h

SPM-HEP-009 *back*

Description: Training in oral communication and pedagogy through preparation and practical implementation. Students design an educational activity for elementary school pupils on a scientific or technological topic (coding, physics, math, etc.). They will create the teaching materials and deliver the lesson in CM1 or CM2 classes (4th or 5th grade), under the supervision of the classroom teacher. The project may involve the FabLab. In semester 6, continuation and completion of the EntreElèves science outreach project started in semester 5. Students finalize their teaching materials and prepare their presentations. The assessment, which involves the classroom teachers, is based on the students' in-class intervention (in pairs or groups of three).

Learning outcomes: At the end of this course, students will have had the experience of having to construct a communication adapted to an audience very different from their own, having made pedagogical choices to successfully get the message across. They will also have had the demanding experience of a real-life communication situation, which implies a certain degree of charisma.

Evaluation methods: Evaluation intervention in classroom and deliverables

Evaluated skills:

- Management
- Business Intelligence

Collaborative Scientific Project 2

Course supervisor: Damien Rontani

Total: 15.5 h **Projet:** 15.5 h

SPM-PRJ-008 *back*

Description: The project topic is part of the specialization in Physical Engineering. It is carried out over two semesters, S05 and S06, as a two-phase collaborative effort. It may be proposed by the teaching team, an industrial or academic partner, or chosen by the students themselves as a personalized subject. The Collaborative Scientific Project (PSC) builds on the skills developed in the Research Initiation course, also followed during semesters S05 and S06. It is structured as follows: During S05, students focus on a detailed literature review, aimed at establishing the scientific and technical background of the project, identifying current challenges in the field, and formulating a clear and well-founded research question. During S06, the project continues with the experimental, numerical, or theoretical implementation of the proposed solutions, the critical analysis of the obtained results, and the dissemination of the work in two formats: (i) a scientific oral presentation, intended for an academic audience; (ii) a public outreach deliverable in digital format (e.g., video, scientific animation, blog article), aimed at a general audience and designed to present the purpose and outcomes of the PSC in just a few minutes.

Learning outcomes: At the end of the project, students will be able to: AA1: Search, analyze, and synthesize scientific information from the state of the art – AA2: Define a research question and design an appropriate problem-solving approach. – AA3: Carry out a scientific investigation (experimental, numerical, or theoretical). – AA4: Critically interpret the results obtained. – AA5: Communicate the project outcomes effectively, both in writing and orally, to scientific and non-specialist audiences. – AA6: Collaborate effectively within a project team, demonstrating autonomy, organization, and a sense of responsibility.

Evaluation methods: Project report, deliverables (e.g., source code, experimental prototype, multimedia files), and oral presentation

Evaluated skills:

- Physical Engineering Design
- Physical Modeling
- Data Processing
- Management
- Business Intelligence

Economic, Industrial and Financial Systems

Course supervisor: Hervé Frezza-Buet, Damien Rontani

Total: 18.0 h **CM:** 18.0 h

SPM-HEP-005 *back*

Description: This course offers a critical examination of contemporary economic, industrial, and financial systems through their origins, dynamics, and impacts. Building on a theoretical foundation, it explores the tensions between economic imperatives and environmental limits. Discussions with field practitioners (elected officials, business leaders) will enrich the reflection by confronting theoretical concepts with industrial and territorial realities.

Learning outcomes: By the end of this course, students will understand the foundations and mechanisms of current economic, industrial, and financial systems. They will be able to analyze their interactions and will gain tools to explore alternative models that align with contemporary social and ecological challenges.

Evaluation methods: The assessment will be based on a report prepared by groups of three students, developed in addition to class hours.

Evaluated skills:

- Business Intelligence

Commons

Course supervisor: Hervé Frezza-Buet, Damien Rontani

Total: 12.0 h **CM:** 12.0 h

SPM-HEP-006 *back*

Description: This course offers an introduction to the commons, exploring their conceptual, legal, and economic foundations, as well as their role in the emergence of more open, sustainable, and collaborative production models. The course is structured around three main themes: first, the principles of the commons, their historical development, legal frameworks, and the limits of their implementation; second, the economic models that allow open source and low-tech projects to grow while staying true to their core values; and finally, the challenges related to open data, illustrated through geographic data, with a focus on privacy protection tools, regulatory frameworks, and emerging issues linked to artificial intelligence.

Learning outcomes: At the end of this course, students will be aware of the existence of commons and the free economy; they will understand their potential, challenges, and the tools for implementation, management, and governance.

Evaluation methods: Students will be asked to imagine a project involving open data and to present the potential value it could create, identify the resources to be secured, and anticipate potential challenges.

Job Application Preparation

Course supervisor: Hervé Frezza-Buet, Damien Rontani

Total: 15.0 h **CM:** 11.0 h, **TP:** 4.0 h

SPM-HEP-023 *back*

Description: The aim of this course is to develop students' career management skills. It will first help them identify their first job opportunity, go through the recruitment process successfully, and transition into the professional world. Later, these skills will support them when they wish to change positions or switch sectors. Finally, the course will provide insights for the day they find themselves in a recruiting role.

Learning outcomes: By the end of this course, students will be prepared for all stages of the recruitment process — before, during, and after job application.

Evaluation methods: The evaluation will be based on observations of the students' involvement.

Sport S06

Course supervisor: Hervé Frezza-Buet

Total: 21.0 h | **TD:** 21.0 h

1SL9000 *back*

Description: Beyond the development of motor skills (physical, technical, and tactical), physical education courses aim to help students develop personal skills related to self-awareness and self-control, as well as interpersonal skills such as teamwork, active listening, communication, and group facilitation.

Execution Internship

Course supervisor: Hervé Frezza-Buet, Damien Rontani

SPM-STA-001 *back*

Description: This first internship aims to confront students with the realities of the business world. During this internship, they take on an operational role and participate in various tasks to understand the challenges and difficulties faced by a worker.This internship also offers students the opportunity to grasp how a company functions and how decisions are communicated from the top down through the hierarchy. It helps develop the knowledge necessary for a thorough understanding of the operator's job and its key role as the foundation of any product or service production process. The internship must last at least 5 weeks and take place between semesters S6 and S7. It must be carried out in an environment conducive to acquiring the required knowledge. In particular, this requires the presence of close supervision and integration into a team composed of a sufficient number of operators performing the same type of tasks.

Learning outcomes: At the end of this internship, the student will be able to describe the company structure as perceived by different employees and compare it with the theoretical structure, illustrate the difficulties of operational tasks, observe human relationships in the workplace, and discuss hierarchical relationships within the company.

Evaluation methods: Pass/Fail evaluation based on the submission of an internship report.

Foreign Languages and Culture 1

Course supervisor: Elisabeth Leuba

Total: 21.0 h **TD:** 21.0 h

LV1S06 *back*

Description: The first foreign language is generally English. Students are divided into level groups ; in class, work is not only focused on the 4 language competences but also on various topics studied in depth according to students' levels. Topics cover a range of fields, such as civilisation, society and the professional world. Limited class size enables active participation and significant improvement in the language. The educational approach is varied: group work, class presentations, specific exercises, research, debates, etc.

Learning outcomes: At the end of the course, students will have improved their ability to communicate in an international professional, academic or personal context.

Evaluation methods: Assessment will be by continuous assessment according to criteria to be determined by each teacher, taking into account personal investment in the course. Each course will be marked out of 20 at the end of the semester.

Evaluated skills:

- Management

Foreign Languages and Culture 2

Course supervisor: Beate Mansanti

Total: 21.0 h **TD:** 21.0 h

LV2S06 *back*

Description: Students are offered a range of second foreign languages at different levels, including for beginners. Students are divided into level groups; in class, work is not only focused on the 4 language competences but also on various topics studied in depth according to students' levels. Topics cover a range of fields, such as civilisation, society and the professional world. Limited class size enables active participation and significant improvement in the language. The educational approach is varied: group work, class presentations, specific exercises, research, debates, etc.

Learning outcomes: At the end of the course, students will have improved their ability to communicate in an international professional, academic or personal context.

Evaluation methods: Assessment will be by continuous assessment according to criteria to be determined by each teacher, taking into account personal investment in the course. Each course will be marked out of 20 at the end of the semester.

Evaluated skills:

- Management