Course catalogue

Engineer Specializing in Physics

Second Year

Metz Campus of CentraleSupélec

last update: January 25, 2026

Semester 7

ISP-PHY-S07-16		**Physics S07**	**9 ECTS**
SPM-PHY-012	2	Light-Matter Interaction and Lasers	21.0 h
SPM-PHY-015	2	Introduction to Quantum Optics	24.0 h
SPM-PHY-014	3	Modern Optics	31.5 h
SPM-PHY-013	2	Physics of condensed matter	24.0 h

ISP-PHY-S07-37		**Engineering Physics S07**	**4 ECTS**
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SPM-PHY-016	2	Physics for Quantum Engineering	24.0 h

ISP-PHY-S07-19		**Mathematics S07**	**4 ECTS**
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PM-MAT-006	1	Advanced Numerical Methods	24.0 h

ISP-PHY-S07-24		**Engineering and Systems S07**	**9 ECTS**
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ISP-PHY-S07-10		**Humanities Management and Business Development S07**	**4 ECTS**
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SPM-HEP-013	P/F	Conferences	10.0 h
SPM-HEP-019	1	Human ressources Management	18.0 h
SportS07	P/F	Sport S07	21.0 h

ISP-PHY-S07-04		**Modern Languages S07**	**4 ECTS**
LV1S07	1	Foreign Languages and Culture 1	21.0 h
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Semester 8

ISP-PHY-S08-21		**Engineering Physics S08**	**9 ECTS**
SPM-PHY-018	1	Introduction to Nanotechnologies	36.0 h
SPM-INF-004	1	Introduction to Quantum Computing	35.5 h
SPM-PHY-019	1	Introduction to Photonics	36.0 h

ISP-PHY-S08-26		**Computing and Data Sciences S08**	**4 ECTS**
SPM-INF-025	1	Machine Learning and Data Sciences 1	28.5 h
SPM-INF-026	1	Machine Learning and Data Sciences 2	19.5 h

ISP-PHY-S08-29		**Project and research S08**	**6 ECTS**
SPM-PRJ-09	5	Innovation and Research Project	60.0 h
SPM-PHY-020	1	Seminar Series : Research and Developpemnt in Engineerinng Physics	12.0 h

ISP-PHY-S08-11		**Humanities Management and Business Development S08**	**7 ECTS**
SPM-HEP-011	1	Engineer, environment and society	14.0 h
SPM-HEP-018	1	Controversy	18.0 h
SPM-HEP-017	2	Systems engineering	21.5 h
SportS08	P/F	Sport S08	21.0 h
SPM-STA-002	4	Engineering internship	0.0 h

ISP-PHY-S08-05		**Modern Languages S08**	**4 ECTS**
LV1S08	1	Foreign Languages and Culture 1	21.0 h
LV2S08	1	Foreign Languages and Culture 2	21.0 h

Light-Matter Interaction and Lasers

Course supervisor: Damien Rontani

Total: 21.0 h **CM:** 13.5 h, **TD:** 3.0 h, **TP:** 3.0 h

SPM-PHY-012 *back*

Description: This course presents the fundamental concepts of light–matter interaction using the semiclassical formalism, in which the electronic structure and dynamics of matter are described within quantum mechanics, while the electromagnetic radiation field is treated classically. The course develops the theoretical framework necessary to understand absorption, spontaneous emission, and stimulated emission processes, with particular emphasis on their physical interpretation and quantitative description. These mechanisms are introduced through simple atomic models and form the basis for analyzing optical transitions and energy exchange between light and matter.

On the basis of these fundamental interactions, the course examines the operating principles of lasers (Light Amplification by Stimulated Emission of Radiation). Key elements of laser systems are discussed, including population inversion, optical gain, and resonant cavities. The main dynamical regimes of laser operation are analyzed, ranging from continuous-wave emission to various pulsed regimes. Finally, selected applications of lasers are presented, with particular emphasis on atomic physics applications such as laser-based manipulation of atomic motion, laser cooling, and trapping techniques.

Bibliography:

- Ref. [1] : B.E.A. Saleh, M.C. Teich, Fundamental of Photonics, Wiley (2007)
- Ref. [2] : M. Sargent, M.O. Scully, W.E. Lamb, Laser Physics, CRC Press (2019)
- Ref. [3] : C. Cohen-Tannoudji, J. Dupont-Roc, G. Grynberg, Processus d interaction entre photons et atomes, EDP Science CNRS Edition (2001)

Learning outcomes: AA1: Understanding of transition probabilities and atom–radiation interaction – AA2: In-depth knowledge of the fundamental principles and basic properties of lasers – AA3: Mastery of the elements of statistical optics and their application to laser coherence and linewidth – AA4: Identification and analysis of the various applications of lasers across different scientific and technological fields

Evaluation methods: Written test, 1h30

Evaluated skills:
- Physical Engineering Design
- Physical Modeling

CM:

1. A compléter (12.0 h)
2. Séminaire Industriel (1.5 h)

TD:

1. A compléter (3.0 h)

TP:

1. A compléter (3.0 h)

Introduction to Quantum Optics

Course supervisor: Nicolas Javahiraly

Total: 24.0 h — **CM:** 10.5 h, **TD:** 7.5 h, **TP:** 6.0 h

SPM-PHY-015 *back*

Description: Quantum optics has become a major branch of quantum physics in recent years and forms the technological foundation for various applications, such as quantum cryptography and quantum computing. The main objective of this course is to provide an accessible overview of quantum optics and its diverse applications at the L3/M1 level (second year of the program), emphasizing an intuitive understanding of physical phenomena while incorporating the necessary mathematical developments.

The course is structured around two main themes: the concept of photons and their statistics. The second part presents the theoretical development of electromagnetic field quantization and the properties of non-classical states of light. Applications are also explored within the framework of quantum information processing. The course includes tutorials with exercise sets designed to consolidate understanding of essential concepts, as well as photonics lab sessions to illustrate applications of quantum optics in cryptography and information processing.

Bibliography:

- Ref. [1]] : M. Fox, Quantum Optics. An Introduction, Oxford University Press, Master Series in Physics (2006)
- Ref. [2] : C. Gerry, P. Knight. Introductory Quantum Optics, Cambridge University Press, 1st Ed. (2004)

Learning outcomes: AA1: Ability to identify the key steps in the quantization of electromagnetic phenomena – AA2: Knowledge of the fundamental principles of quantum light sources – AA3: Experimental implementation of quantum optics concepts for applications in telecommunications.

Evaluation methods: Written Exam

Evaluated skills:
- Physical Engineering Design
- Physical Modeling

CM:

1. Introduction (1.5 h)
2. Notion de Photons-1/2 (1.5 h)
3. Notion de Photons-2/2 (1.5 h)
4. Quantification du champ électromagnétique -1/2 (3.0 h)
5. Applications au traitement quantique de l'information (3.0 h)

TD:

1. Notion de Photons (1.5 h)
2. Quantification du champ électromagnétique -2/2 (3.0 h)
3. Quantification du champ électromagnétique (1.5 h)
4. Applications au traitement quantique de l'information (1.5 h)

TP:

1. Notion de Photons (3.0 h)
2. Applications au traitement quantique de l'information (3.0 h)

Modern Optics

Course supervisor: Nicolas Marsal

Total: 31.5 h **CM:** 18.0 h, **TD:** 7.5 h, **TP:** 3.0 h

SPM-PHY-014 *back*

Description: Modern optics is a branch of science focused on the study of light and its properties for use in information analysis and processing. Key concepts include geometrical optics, wave optics, interference, diffraction, polarization, coherence, and, in particular, Fourier optics. Fourier optics provides the tools to understand and design imaging systems, holographic techniques, and spatial and frequency-domain information processing methods. The course aims to give students a solid understanding of the fundamental principles and their applications in modern optical systems.

Tutorials and laboratory sessions enable students to acquire both theoretical and experimental skills, particularly in the analysis and design of imaging systems and holographic devices. Through practical exercises and experiments involving Fourier optics, students learn to process and analyze optical information, manipulate light beams, and apply essential mathematical concepts for optical information processing. The course prepares students to develop and analyze complex optical systems for scientific and technological applications.

Learning outcomes: AA1: Understand the interaction between light and matter through absorption, emission, and scattering processes – AA2: Master light manipulation techniques, including diffraction, polarization, and advanced optical devices – AA3: Analyze complex optical situations and solve problems related to specific applications – AA4: Understand the concepts of coherent optics, including interference, coherence functions, and holography – AA5: Be able to carry out an optical device design project using commercial or industrial software.

Evaluation methods: Written test, 3h

Evaluated skills:
- Physical Engineering Design
- Physical Modeling

CM:

1. Propriétés optiques des solides (3.0 h)
2. Optique géométrique (3.0 h)
3. Optique ondulatoire (4.5 h)
4. Optique de Fourier (7.5 h)

TD:

1. Propriétés optiques des solides (1.5 h)
2. Optique géométrique (1.5 h)
3. Optique ondulatoire (1.5 h)
4. Optique de Fourier (1.5 h)
5. CGH (1.5 h)

TP:

1. Holographie (3.0 h)

Physics of condensed matter

Course supervisor: Nicolas Marsal

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

SPM-PHY-013 *back*

Description: Building on the concepts introduced in the first year on semiconductors and solid-state physics, this course explores a range of material behaviors, beginning with transport phenomena and extending to magnetism and superconductivity. These topics are examined with a focus on their distinctive physical properties, providing students with a deeper understanding of the mechanisms governing condensed matter systems. The course emphasizes both theoretical foundations and illustrative examples to highlight how fundamental principles manifest in real materials.

The study of condensed matter is continually advanced by the creation and investigation of new classes of materials. A key example discussed in the course is topological insulators, which are distinguished from conventional materials by the fact that their phase transitions do not involve symmetry breaking, classifying them as non-trivial matter. Through this and other examples, students gain insight into modern developments in material science and the unique behaviors that arise from complex physical interactions.

Bibliography:

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

Learning outcomes: AA1: Understand transport phenomena in solids, including electronic transport, scattering, and thermal properties – AA2: Have knowledge of magnetic phenomena, superconductivity, and topological properties – AA3: Be able to follow recent advances in condensed matter physics and adapt to new discoveries and emerging technologies.

Evaluated skills:

- Physical Modeling

CM:

1. Phénomène de Transports quantiques (3.0 h)
2. Matériaux magnétiques (3.0 h)
3. La Supraconductivité (4.5 h)
4. Les isolants topologiques (4.5 h)

TD:

1. Phénomène de Transports quantiques (1.5 h)
2. Matériaux magnétiques (1.5 h)
3. La Supraconductivité (1.5 h)
4. Les isolants topologiques1/2 (1.5 h)
5. Les isolants topologiques2/2 (1.5 h)

Quantum Information and Computation

Course supervisor: Thomas Decultot

Total: 24.0 h **CM:** 15.0 h, **TD:** 3.0 h, **TP:** 6.0 h

SPM-PHY-017 *back*

Description: The Quantum Information and Computation course introduces students to the fundamental and advanced concepts of quantum mechanics that are essential for understanding and designing quantum technologies. The course covers the density matrix formalism, which allows a complete description of quantum states, and explores superposition, measurement, and entanglement. Students learn to quantify correlations in multipartite quantum systems using measures such as entropy and gain a solid foundation in quantum information theory, including encoding, processing, and transfer of information in quantum systems.

The course also provides a practical introduction to quantum computation. Students study elementary quantum circuits, the evolution of qubits under quantum gates, and the implementation of basic quantum algorithms. Emphasis is placed on linking theory with applications, including quantum communication, computation, and emerging quantum devices. By the end of the course, students acquire both analytical skills to model and analyze quantum systems and practical experience to simulate, design, and interpret quantum information processes, preparing them for advanced studies or research in quantum engineering..

Bibliography:

- Ref3 : M.A. Nielsen I.L. Chuang, Quantum Computation and Quantum Information, Cambridge University Press (2010)
- Ref4 : S. Barnett, Quantum Information, Oxford University Press (2009)

Learning outcomes: AA1: Manipulation and calculation using the density-operator formalism – AA2 : Use quantum information tools to analyze elementary quantum communication architectures – AA4: Knowledge of current technologies used in quantum computers and their limitations – AA5: Mathematical analysis and processing of elementary quantum circuits – AA6: Understanding and numerical implementation of basic quantum algorithms

Evaluation methods: Written Exam

Evaluated skills:
- Physical Engineering Design
- Physical Modeling
- Systems Analysis

CM:

1. Outils pour la théorie de l'information quantique -1/2 (1.5 h)
2. Outils pour la théorie de l'information quantique -2/2 (1.5 h)
3. Communications quantiques (3.0 h)
4. Introduction aux circuits quantiques (3.0 h)
5. Introduction aux algorithmes quantiques (4.5 h)
6. Ouverture aux technologies des calculateurs quantiques (1.5 h)

TD:

1. Introduction aux circuits quantiques (1.5 h)
2. Introduction aux algorithmes quantiques -1/2 (1.5 h)

TP:

1. Introduction aux circuits quantiques (3.0 h)
2. Introduction aux algorithmes quantiques (3.0 h)

Physics for Quantum Engineering

Course supervisor: Thomas Tuloup, Corentin Bertrand

Total: 24.0 h **CM:** 15.0 h, **TD:** 9.0 h

SPM-PHY-016 *back*

Description: The Physics of Quantum Engineering course provides students with a deep understanding of open quantum systems and the effects of dissipation and noise on quantum architectures. Building on the density-matrix formalism, the course introduces the principles required to describe mixed quantum states and the realistic dynamics of quantum devices. Students study the physical mechanisms leading to decoherence and energy relaxation, which are central limitations in practical quantum technologies, and learn how these effects impact the operation of quantum circuits and communication systems.

A key component of the course is the Lindblad master equation, presented as a general framework for modeling dissipative and noisy quantum dynamics. Students gain experience applying this formalism to analyze quantum systems under realistic conditions, including multipartite setups and coupled qubit architectures. The course also situates these concepts within a broader scientific and technological context, emphasizing contemporary developments in quantum computation, quantum communication, and emerging quantum devices. By the end of the course, students acquire both theoretical insight and practical skills to model, analyze, and interpret the dynamics of quantum systems affected by noise and dissipation, preparing them for advanced studies or research in quantum engineering.

Bibliography:

- Ref1 : C. Gardiner and P. Zoller, Quantum noise (Springer-Verlag) (2004)
- Ref2 : M. Joffre, Physique Quantique Avancée. Cours de lEcole Polytechnique (2023)
- Ref3 : M.A. Nielsen I.L. Chuang, Quantum Computation and Quantum Information, Cambridge University Press (2010)

Learning outcomes: AA1: Manipulation and calculation using the density-matrix formalism for pure and mixed quantum states – AA2: Modeling and analysis of open quantum systems, including dissipative dynamics and the effects of noise on quantum architectures – AA3: Knowledge of current technologies used in quantum computers (NISQ devices) and understanding their limitations due to dissipation and noise – AA4: Application of the Lindblad master equation to simulate and analyze realistic quantum dynamics and elementary quantum circuits under dissipation – AA5: Ability to model, simulate, and interpret the performance of quantum systems, including entanglement and entropy in multipartite setups, taking into account dissipation and noise effects.

Evaluation methods: Written Exam and Continuous Evaluation

Evaluated skills:

- Physical Modeling

CM:

1. Formalisme de la matrice densité et systèmes multi-parties (4.5 h)
2. Quantification des phénomènes vibratoires et Introduction à l'optique quantique-1/3 (3.0 h)
3. Quantification des phénomènes vibratoires et Introduction à l'optique quantique-2/3 (3.0 h)
4. Quantification des phénomènes vibratoires et Introduction à l'optique quantique3/3 (1.5 h)
5. Intrication quantique, Mesure et Décohérence (3.0 h)

TD:

1. Formalisme de la matrice densité et systèmes multi-parties (1.5 h)
2. Quantification des phénomènes vibratoires et Introduction à l'optique quantique-1/3 (1.5 h)
3. Quantification des phénomènes vibratoires et Introduction à l'optique quantique-2/3 (1.5 h)

4. Quantification des phénomènes vibratoires et Introduction à l'optique quantique-3/3 (1.5 h)
5. Intrication quantique, Mesure et Décohérence-1/2 (1.5 h)
6. Intrication quantique, Mesure et Décohérence-2/2 (1.5 h)

Optimization

Course supervisor: Michel Barret

Total: 25.0 h — **CM:** 10.5 h, **TD:** 4.5 h, **TP:** 9.0 h

SPM-MAT-004 *back*

Description: In this course, students are expected to acquire and master various fundamental aspects of continuous optimization. The following concepts will be covered and implemented in practice: formulation of optimization problems, conditions for the existence of global and local minimizers, convexity, duality, Lagrange multipliers, first-order methods, linear programming. The use of differentiable programming will be presented in practical work. Stochastic gradient-free methods, such as CMAES and PSO, will also be covered.

Learning outcomes: By the end of this course, students will master the fundamental concepts of continuous optimization (conditions for the existence of global and local minimizers, convexity, duality, Lagrange multipliers, first-order methods, linear programming, stochastic methods).

Evaluation methods: 1h written test, can be retaken

Evaluated skills:
- Physical Modeling
- Data Processing

CM:

1. Bases de l'optimisation 1/2 (1.5 h)
2. Bases de l'optimisation 2/2 (1.5 h)
3. Convexité, quelques algorithmes itératifs (1.5 h)
4. Dualité (1.5 h)
5. Programmation linéaire (1.5 h)
6. Méthode des multiplicateurs de Lagrange (1.5 h)
7. Méthodes stochastiques gradient-free (1.5 h)

TD:

1. Dualité (1.5 h)
2. Programmation linéaire (1.5 h)
3. Méthode des multiplicateurs de Lagrange (1.5 h)

TP:

1. Bases de l'optimisation (3.0 h)
2. Convexité, quelques algorithmes itératifs (3.0 h)
3. Méthodes stochastiques gradient-free (3.0 h)

Advanced Numerical Methods

Course supervisor: Damien Rontani

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

PM-MAT-006 *back*

Bibliography:

- Ref1 : référence à indiquer

Evaluation methods: Labwork report

Evaluated skills:

- Physical Modeling

CM:

1. à définir (3.0 h)
2. Simulation des équations aux dérivées partielles (EDP) hyperboliques (3.0 h)
3. Simulation des équations aux dérivées partielles (EDP) paraboliques (3.0 h)
4. Séminaire Industriel (1.5 h)

TD:

1. à définir (1.5 h)
2. Simulation des équations aux dérivées partielles (EDP) hyperboliques (1.5 h)
3. Simulation des équations aux dérivées partielles (EDP) paraboliques (1.5 h)

TP:

1. à définir (3.0 h)
2. Simulation des équations aux dérivées partielles (EDP) hyperboliques (3.0 h)
3. Simulation des équations aux dérivées partielles (EDP) paraboliques (3.0 h)

System and Control

Course supervisor: Jean-Luc Collette

Total: 28.5 h **CM:** 15.0 h, **TD:** 4.5 h, **TP:** 9.0 h

SPM-AUT-002 *back*

Description: The second-year Dynamic Systems Control course aims to provide students with the skills necessary to understand the fundamental principles of dynamic systems. This will equip them to analyze and implement effective control systems in a wide range of applications, with an emphasis on understanding theoretical concepts as well as their practical application.

Bibliography:

- Ref. [1] : C.T. Chen, Linear Systems Theory and Design. Oxford University Press, 3rd Ed. (1999)

Learning outcomes: Upon completion of this second-year course, the student will be able to implement system identification methods. They will be able to develop control laws that utilize available measurements and meet optimal criteria associated with the constraints imposed on the system.

Evaluation methods: Labwork evaluation.

Evaluated skills:

- Physical Modeling
- Data Processing
- Systems Analysis

CM:

1. Représentation d'état : Systèmes commandables, stabilisables (1.5 h)
2. Représentation d'état : Systèmes observables, détectables (1.5 h)
3. Représentation d'état : Forme canonique de Kalman (1.5 h)
4. Commande par retour d'état : Commande par placement des pôles (1.5 h)
5. Commande par retour d'état : Commande linéaire quadratique (1.5 h)
6. Commande par retour d'état : compléments (1.5 h)
7. Observateurs : Réglage avec placement des pôles (1.5 h)
8. Observateurs : Réglage avec filtre de Kalman (1.5 h)
9. Observateurs : Commande LQG (1.5 h)
10. Séminaire Industriel (1.5 h)

TD:

1. TD Représentation d'état (1.5 h)
2. TD Commande par retour d'état (1.5 h)
3. TD Observateurs (1.5 h)

TP:

1. TP Représentation d'état (3.0 h)
2. TP Commande par retour d'état (3.0 h)
3. TP Observateurs (3.0 h)

Electronic : Conception and Integration

Course supervisor: Yves Houzelle

Total: 33.0 h **CM:** 12.0 h, **TD:** 6.0 h, **TP:** 12.0 h

SPM-ELE-002 *back*

Description: The second-year core-course in Electronics aims to deepen the concepts introduced in the first-year course. In particular, it covers the basic building blocks (transistors) used in the design of integrated circuits. An in-depth study of these building blocks makes it possible to understand the imperfections of integrated components, including their frequency limitations, thermal aspects, and power consumption.

Bibliography:

- Ref. [1] : P. Aldebert, Modélisation des composants usuels pour la conception et l'analyse, CentraleSupélec, 01134/01, 2004
- Ref. [2] : G. Tourneur, Introduction à l'électroniqueanalogique, CentraleSupélec, 17189/01, 2017/2018
- Ref. [3] : J. Oksman, J-P Zsylowicz, P. Benabes, G. Seignier, Y. Houzelle, Systèmes logiques et électronique associée, Volumes 1 et 2, CentraleSupélec, 2020/2021.

Learning outcomes: AA1: Understand the concepts of analog and digital electronics: component modeling, biasing, linearization, large-signal analysis, feedback and loop control, impedance matching, synchronous sequential logic, and frequency-domain behavior - AA2: Master the main CAD and simulation tools - AA3: Be able to analyze electronic functions using appropriate models - AA4: Be able to design and size electronic functions while taking into account interfaces between components and with the external environment - AA5: Be able to specify an electronic system and write technical specifications

Evaluation methods: Written test, 3h

Evaluated skills:

- Physical Modeling
- Systems Analysis

CM:

1. Le transistor bipolaire 1 (1.5 h)
2. Le transistor bipolaire 2 (1.5 h)
3. Le transistor bipolaire 1 (1.5 h)
4. Le transistor bipolaire 1 (1.5 h)
5. Le transistor bipolaire 1 (1.5 h)
6. Le transistor bipolaire 1 (1.5 h)
7. Le transistor bipolaire 1 (1.5 h)
8. Le transistor bipolaire 1 (1.5 h)

TD:

1. Le transistor bipolaire TD 1 (1.5 h)
2. Le transistor bipolaire TD 1 (1.5 h)
3. Le transistor bipolaire TD 1 (1.5 h)
4. Le transistor bipolaire TD 2 (1.5 h)

TP:

1. Le transistor bipolaire TP 1 (3.0 h)
2. Le transistor bipolaire TP 2 (3.0 h)

3. Le transistor bipolaire TP 1 (3.0 h)
4. Le transistor bipolaire TP 2 (3.0 h)

Signal Processing and Spectral Analysis

Course supervisor: Stéphane Rossignol

Total: 33.0 h — **CM:** 18.0 h, **TD:** 6.0 h, **TP:** 9.0 h

SPM-SIC-002 *back*

Description: The digital world produces large volumes of data of all kinds (audio, images, video, physical measurements) associated with human activities in fields as diverse as healthcare, telecommunications, industry, and the environment. Extracting information from these signals is increasingly necessary for decision-making (e.g., medical diagnosis), information encoding (e.g., data compression), the analysis of physical phenomena (e.g., detection of mechanical faults), and signal restoration (e.g., removal of unwanted noise from an audio signal).

Signal processing lies at the interface of mathematics, physics, and computer science. Mathematical concepts provide tools for signal representation and the operators required for their manipulation. Physical models make it possible to link measured data to the information sought. Finally, computer science is essential for the implementation of any digital processing.

Bibliography:

- Ref. [1] : A.V. Oppenheim and R.W. Schafer, Discrete Time Signal Processing, Prentice Hall
- Ref. [2] : G. Fleury, Analyse Spectrale. Méthodes non-paramétriques et paramétriques, Ellipses (2001)

Learning outcomes: At the end of the second-year course, students will be able to understand and use deterministic (AA1) and statistical (AA2) signal processing methods to solve various problems in information sciences, such as filtering (AA3), advanced spectral analysis (AA4), and others. These problems arise in applications as diverse as automatic recognition of audio signals (speakers, etc.), radar source localization, climate data analysis, medical image reconstruction in MRI, gravitational wave detection in astrophysics, and the development of future-generation cellular networks (5G, IoT).

Evaluated skills:

- Physical Modeling
- Data Processing

CM:

1. Introduction (1.5 h)
2. Systèmes 1er et 2ème ordre (Bode) (1.5 h)
3. Filtres analogiques (1.5 h)
4. Filtres numériques (1.5 h)
5. Propriétés temporelles des signaux aléatoires : Stationnarités/Ergodicité (1.5 h)
6. Propriétés spectrales des signaux aléatoires (1.5 h)
7. Signaux AR/MA/ARMA (1.5 h)
8. Compléments à l'analyse spectrale standard : périodogrammes (Daniell/Bartlett/Welch) et corrélogramme (1.5 h)
9. Analyse spectrale avancée – Ondelettes (1.5 h)
10. Analyse spectrale avancée – MUSIC, Pisarenko, Prony (1.5 h)
11. Représentations parcimonieuses (1.5 h)
12. Décompositions d'un signal ('pursuit') (1.5 h)

TD:

1. Filtrage (1.5 h)
2. Analyse spectrale standard (1.5 h)

3. Analyses spectrales autres (1.5 h)
4. Parcimonie (1.5 h)

TP:

1. Design de filtres numériques (1.5 h)
2. Complément sur la TF des signaux discrets (1.5 h)
3. Spectres autorégressifs et de MUSIC (3.0 h)
4. Représentations parcimonieuses des signaux (3.0 h)

Business Management and Transformation

Course supervisor: Francis Dorveaux

Total: 26.5 h **CM:** 5.5 h, **TD:** 12.0 h, **TP:** 8.5 h

SPM-HEP-014 *back*

Description: The objective of this course is to explore the diversity of businesses and their integration into a global socio-economic and environmental context, as well as the dynamics they generate. The pedagogical approach combines theoretical input through lectures with a group fieldwork investigation, allowing future entrepreneurs to be confronted with the realities of business creation and development.

Learning outcomes: By the end of this course, students will have gained a comprehensive understanding of the entrepreneurial ecosystem and the forces that drive it.

Evaluation methods: MCQ (30 min), individual oral interactions

Evaluated skills:
- Business Intelligence

CM:

1. Introduction (1.0 h)
2. Panorama des entreprises (2.0 h)
3. Synthèse et débat (2.5 h)

TD:

1. TD 1 : Les théories modernes de l'entreprise + explications des attendus des TD 2 à 6 (1.5 h)
2. TD 2 : Les processus "colonne vertébrale" de l'organisation (1.5 h)
3. TD 3 : La dynamique externe (1.5 h)
4. TD 4 : Transformation des entreprises (3.0 h)
5. TD 5 : Business Development 1 (à préciser) (1.5 h)
6. TD 6 : Business Development 2 (à préciser) (3.0 h)

TP:

1. 1ère visite en entreprise (4.5 h)
2. 2ème visite en entreprise (4.0 h)

Conferences

Course supervisor: Damien Rontani, Hervé Frezza-Buet

Total: 10.0 h **CM:** 10.0 h

SPM-HEP-013 *back*

Description: This course consists of a series of seminars.

Learning outcomes: By the end of these lectures, students will have broadened their perspective on environmental, economic, societal, and ethical issues, depending on the expertise of the speakers.

CM:

1. tdb (10.0 h)

Human ressources Management

Course supervisor: Damien Rontani, Hervé Frezza-Buet

Total: 18.0 h | **TD:** 18.0 h

SPM-HEP-019 *back*

Description: This course has a dual objective: on the one hand, to equip students with knowledge of their rights and obligations in relation to HR practices, particularly during recruitment; and on the other hand, to enable engineers transitioning into managerial roles to collaborate effectively with management and HR departments.

Learning outcomes: By the end of this course, students will have acquired a foundational understanding of labor law and HR functions, which will be useful both as employees and in their supervisory or managerial responsibilities.

Evaluated skills:

- Business Intelligence

TD:

1. tbd (18.0 h)

Sport S07

Course supervisor: Hervé Frezza-Buet

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

SportS07 *back*

TD:

1. Cours de sport (21.0 h)

Foreign Languages and Culture 1

Course supervisor: Elisabeth Leuba

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

LV1S07 *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

TD:

1. Cours (21.0 h)

Foreign Languages and Culture 2

Course supervisor: Beate Mansanti

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

LV2S07 *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

TD:

1. Cours (21.0 h)

Introduction to Nanotechnologies

Course supervisor: Jean-Paul Salvestrini

Total: 36.0 h **CM:** 25.5 h, **TD:** 9.0 h

SPM-PHY-018 *back*

Description: The properties of a material at the macroscopic scale are generally determined by its chemical composition and atomic structure. However, this rule no longer applies to objects of nanometric size, whose physical, chemical, and functional properties also depend on their size, shape, and environment. This specificity opens the door to numerous innovative applications. The objective of this course is to introduce students to the fundamentals of nanoscience and nanotechnology, highlighting the key concepts that distinguish nanoscale systems from conventional materials and devices.

The course covers both nanomaterials and nanotechnologies in a broader sense, addressing surface properties, nanostructuring methods, as well as the principles of design and fabrication of nanoscale devices. It also deals with fundamental questions related to the existence and behavior of nano-objects, such as their structure, morphology, and stability. Through selected examples, various properties of nanoscale systems are examined, including optical, electronic, transport, magnetic, chemical, thermodynamic, mechanical, and biological aspects. Overall, the course provides students with a comprehensive view of nanotechnologies and their potential applications across a wide range of scientific and industrial fields.

Bibliography:

- Ref. [1] : S.M. Linsay, Introduction to Nanosciences, Oxford University Press (2008)
- Ref. [2] : C. Binns, Introduction to Nanoscience and Nanotechnology, Wiley-VCH, 2nd Ed. (2021)

Learning outcomes: AA1: Explain the fundamental concepts of nanotechnology, including nanometric scales, quantum size effects, and the unique properties of nanomaterials – AA2: Understand nanoscale components and devices, as well as their optical, mechanical, and electronic operation – AA3: Identify different growth and nanostructuring techniques – AA4: Apply acquired knowledge to analyze and solve complex problems related to nanotechnology.

Evaluation methods: Written test, 1h30

Evaluated skills:
- Physical Engineering Design
- Physical Modeling
- Systems Analysis

CM:

1. Surfaces et nanostructuration (7.5 h)
2. Nano-Objets (7.5 h)
3. Propriétés des nano-objets (10.5 h)

TD:

1. Surfaces et nanostructuration1/2 (1.5 h)
2. Surfaces et nanostructuration2/2 (1.5 h)
3. Nano-Objets1/2 (1.5 h)
4. Nano-Objets2/2 (1.5 h)
5. Propriétés des nano-objets1/2 (1.5 h)
6. Séminaire Industriel (1.5 h)

INTRODUCTION TO QUANTUM COMPUTING

Course supervisor: Damien Rontani, Stéphane Vialle

Total: 35.5 h **CM:** 16.5 h, **TD:** 4.5 h, **TP:** 9.0 h, **Projet:** 5.5 h

SPM-INF-004 *back*

Description: This Quantum Programming and Algorithms course offers a comprehensive dive into the fundamentals and practical applications of quantum accelerators. Students will explore contemporary quantum architectures, including the principles of analog and digital architectures, as well as innovations such as hybrid CPU-QPU, NISQ, and LSQ architectures. The course will cover the formalism of qubits and digital quantum programming, highlighting the importance of superposition and entanglement for quantum computations. The principles and methods of measuring results will also be discussed. An introduction to quantum circuits, including basic gates and early circuits, will enable students to understand the practical basics of quantum programming. Using tools such as QFT, Grover, QPE, and QMC, students will explore classical circuits and their applications, while examining the limitations on NISQ architectures. Finally, students will delve into variational circuits and algorithms, including QAOA and Vxx circuits, and study runtime and performance models for QPUs as well as CPU-QPU loops, familiarizing themselves with the orders of magnitude of current runtimes.

Bibliography:

- Ref. [1] : R. Hundt, Quantum Computing for Programmers, Cambridge University Press (2022)
- Ref. [2] : P. Kaye, R. Laflamme, M. Mosca, An Introduction to Quantum Computing, Oxford University Press (2006)

Learning outcomes: AA1: Identify basic gates and build initial quantum circuits – AA2: Effectively use tools such as QFT, Grover, QPE, and QMC algorithms to solve engineering problems – AA3: Understand and be able to assess the limitations of NISQ architectures and propose appropriate solutions – AA4: Design and implement variational circuits and algorithms, such as QAOA and Vxx – AA5: Evaluate the performance and execution times of quantum algorithms in various contexts, including QPUs and CPU-QPU loops.

Evaluation methods: Assessment of the mini project

Evaluated skills:

- Physical Engineering Design
- Physical Modeling
- Data Processing
- Systems Analysis

CM:

1. Cours d'architectures quantiques (1.5 h)
2. Cours de formalisme pour l'informatique quantique digitale (3.0 h)
3. Cours d'introduction aux portes et circuits quantiques (3.0 h)
4. Cours de présentation des circuits quantiques classiques (4.5 h)
5. Cours de modèles de temps d'exécution et de performance (1.5 h)
6. Cours de présentation des circuits quantiques variationnels (3.0 h)

TD:

1. TD de formalisme et d'analyse de circuits quantiques (1.5 h)
2. TD de conception d'algorithmes quantiques sur QPU (1.5 h)
3. TD de conception d'algorithmes variationnels sur CPU+QPU (1.5 h)

TP:

1. TP de mise en oeuvre de circuits quantiques en qiskit sur simulateur et machines quantiques (3.0 h)
2. TP de conception et mise en oeuvre d'algorithmes quantiques à partir de circuits connus (3.0 h)
3. TP de conception d'une méthode d'optimisation par algorithme variationnel sur CPU+QPU (3.0 h)

Introduction to Photonics

Course supervisor: Marc Sciamanna

Total: 36.0 h **CM:** 16.5 h, **TD:** 7.5 h, **TP:** 10.5 h

SPM-PHY-019 *back*

Description: Photonics is the science and technology that uses light. Lasers, optical fibers, photodetectors, photovoltaic cells, and quantum computing architectures are examples of photonic systems that have been developed since the mid-twentieth century. The introductory course in photonics describes the fundamental physical principles governing the generation, propagation, amplification, and detection of optical electromagnetic waves, thereby providing a deeper understanding of the importance of photonics in both research and industrial applications. Tutorials and laboratory sessions enable students to acquire practical skills, particularly in the simulation and measurement of photonic systems.

Bibliography:

- Ref. [1] : J.-M. Liu, Principles of Photonics, Cambridge University Press (2016)

Learning outcomes: AA1: Explain and identify the key challenges of photonics in relation to economic and technological factors associated with the development of the information and communication society – AA2: Understand the physical mechanisms underlying the most common photonic systems, such as lasers, optical amplifiers, optical fibers, and photodetectors – AA3: Numerically simulate and experimentally measure the fundamental properties and performance of a photonic system – AA4: Apply the acquired concepts to develop an innovative photonic system, based on a scientific and technical specification and by leveraging the state of the art.

Evaluation methods: Written test, 1h30

Evaluated skills:

- Physical Engineering Design
- Physical Modeling

CM:

1. La lumière, onde et particule (3.0 h)
2. Propagation et guides d'onde (4.5 h)
3. Amplification optique (6.0 h)
4. Photodétection (3.0 h)

TD:

1. Propagation optique (3.0 h)
2. Laser (3.0 h)
3. Seminaire Industriel (1.5 h)

TP:

1. Caractérisation d'un système photonique (10.5 h)

Machine Learning and Data Sciences 1

Course supervisor: Sylvie Le Hegarat, Emanuel Aldea

Total: 28.5 h — **CM:** 6.0 h, **TD:** 6.0 h, **TP:** 15.0 h

SPM-INF-025 *back*

Description: This course provides a structured introduction to the fundamental methods of artificial intelligence and machine learning (AI/ML), combining theoretical concepts with hands-on practice. It begins with an overview of general AI and machine learning concepts, including neural networks and supervised and unsupervised learning approaches. The foundations of deep learning are then developed, with particular emphasis on convolutional neural networks (CNNs) and their applications to complex data analysis. All these topics are covered through lectures and practical sessions designed to ensure students gain both conceptual understanding and practical experience with the tools.

The course also explores advanced topics such as reinforcement learning, uncertainty quantification, and physics-informed neural networks (PINNs). These approaches enable the treatment of optimization problems, sequential decision-making, and the modeling of physical systems while incorporating constraints derived from fundamental physical laws. Through case studies and hands-on exercises, the course highlights the potential of these methods for modeling, simulation, and analysis of complex systems in both science and engineering.

Bibliography:

- Ref. [1] : J.N. Kurtz, Data-Driven Modeling & Scientific Computation: Methods for Complex Systems & Big Data, Oxford University Press (2013)

Learning outcomes: AA1: Understand the fundamental principles of AI and machine learning, including neural networks and supervised/unsupervised learning – AA2: Master deep learning and convolutional neural networks for complex data analysis – AA3: Apply reinforcement learning to optimization and sequential decision-making problems – AA4: Integrate uncertainty quantification into AI/ML models – AA5: Use physics-informed neural networks for modeling physical systems – AA6: Combine theory and practice through hands-on exercises and scientific or industrial case studies.

Evaluated skills:

- Physical Modeling
- Data Processing

CM:

1. Réseaux de Neurones (1.5 h)
2. Introduction à l'apprentissage par renforcement (1.5 h)
3. Apprentissage Machine informé par la physique (1.5 h)
4. Quantification des Incertitudes (1.5 h)

TD:

1. Réseaux de Neurones (1.5 h)
2. Introduction à l'apprentissage par renforcement (1.5 h)
3. Apprentissage Machine informé par la physique (1.5 h)
4. Quantification des Incertitudes (1.5 h)

TP:

1. Travaux Expérimentaux (TrEx)1/5 (3.0 h)
2. Travaux Expérimentaux (TrEx)2/5 (3.0 h)

3. Travaux Expérimentaux (TrEx)3/5 (3.0 h)
4. Travaux Expérimentaux (TrEx)4/5 (3.0 h)
5. Travaux Expérimentaux (TrEx)5/5 (3.0 h)

Machine Learning and Data Sciences 2

Course supervisor: Damien Rontani

Total: 19.5 h — **CM:** 4.5 h, **TD:** 4.5 h, **TP:** 9.0 h

SPM-INF-026 *back*

Description: The objective of this course is to provide students with the mathematical methods and tools necessary for exploring, analyzing, and interpreting data in the fields of science and physical engineering. The course presents an overview of classical and advanced statistical techniques, such as principal component analysis (PCA) and orthogonal mode decomposition, with an emphasis on their mathematical formulation and numerical implementation. These approaches enable the identification of underlying structures in data and the efficient synthesis of information for the analysis of complex systems.

The course also covers complementary topics such as spectral analysis, sparse representations, and mathematical model reduction, which are essential for modeling and simulating physical phenomena. Through applied examples and practical exercises, students will learn to combine these methods to process real datasets, optimize models, and extract actionable insights, while developing a critical understanding of the assumptions and limitations inherent in each technique.

Bibliography:

- Ref. [1] : Brunton-Kutz : L. Brunton, J. N. Kutz, Data-Driven Science and Engineering: Machine Learning, Dynamical Systems, and Control, Cambridge University Press (2022)

Learning outcomes: AA1: Apply statistical and mathematical methods to explore and analyze scientific and engineering data – AA2: Implement dimensionality reduction techniques for efficient data representation – AA3: Develop and apply data-driven models for identification and control of complex nonlinear systems – AA4: Use spectral, sparse, and model reduction techniques to extract patterns and simplify complex systems.

Evaluation methods: Written test, 1h30

Evaluated skills:

- Physical Modeling
- Data Processing

CM:

1. Réduction de dimension et transformations (1.5 h)
2. Sciences de données pour l'identification et la commande (1.5 h)
3. Réduction de Modèles (1.5 h)

TD:

1. Réduction de dimension et transformations (1.5 h)
2. Sciences de données pour l'identification et la commande (1.5 h)
3. Réduction de Modèles (1.5 h)

TP:

1. Travaux Expérimentaux (TrEx)1/3 (3.0 h)
2. Travaux Expérimentaux (TrEx)2/3 (3.0 h)
3. Travaux Expérimentaux (TrEx)3/3 (3.0 h)

Innovation and Research Project

Course supervisor: Damien Rontani

Total: 60.0 h **Projet:** 60.0 h

SPM-PRJ-09 *back*

Description: The objectives of this project are to introduce students, both collectively and individually, to a rigorous academic research approach applied to an open-ended question in Physical Engineering (Photonics / Nanosciences / Quantum Systems) proposed by the teaching team, with possible collaborations with partner research institutions. The project begins with a literature review and synthesis. It then continues, in a second phase, with the search for an innovative and creative solution to the problem posed, based on physical modeling, numerical simulations, and/or the realization of an experiment, followed by a critical analysis of the results obtained. Students will be required to formalize their potential findings in the form of a scientific article written in English and a public oral defense that follows the communication standards of internationally adopted scientific conferences (i.e., a time-limited presentation in English followed by a question-and-answer session).

Evaluation methods: Report and defense

Evaluated skills:

- Physical Engineering Design
- Physical Modeling
- Data Processing
- Systems Analysis
- Research / Innovation
- Management

Seminar Series : Research and Developpemnt in Engineerinng Physics

Course supervisor: Damien Rontani

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

SPM-PHY-020 *back*

Description: The course will primarily consist of seminars and will host speakers and researchers mainly from the industrial sector in the field of physical engineering, associated with various ecosystems (e.g., large technology corporations, deep-tech start-ups). It will also include speakers from governmental agencies to address the importance of research in issues related to resilience, sovereignty, and industrial, digital, and ecological transitions. In some cases, these seminars may take the form of round-table discussions and will systematically include question-and-answer sessions with students, followed by a social event organized on the school premises, allowing for informal and meaningful exchanges between students and the speakers.

Evaluated skills:

- Research / Innovation
- Business Intelligence

TD:

1. Seminaires (12.0 h)

Engineer, environment and society

Course supervisor: Julien Colin

Total: 14.0 h **TD:** 14.0 h

SPM-HEP-011 *back*

TD:

1. tbd (14.0 h)

Controversy

Course supervisor: Hervé Frezza-Buet, Damien Rontani

Total: 18.0 h **TD:** 18.0 h

SPM-HEP-018 *back*

Description: The objective of this course is to contribute to students' civic and critical education, enabling them to develop the ability to analyze public debates and engage constructively with differing opinions.

Learning outcomes: By the end of this course, students will be able to recognize the dimensions of a controversy and will be familiar with several techniques for working towards its resolution.

Evaluated skills:

- Business Intelligence

TD:

1. tbd (18.0 h)

Systems engineering

Course supervisor: Virginie Galtier

Total: 21.5 h **CM:** 11.0 h, **TP:** 9.0 h

SPM-HEP-017 *back*

Description: This course introduces the engineering of complex systems, with an emphasis on modern modeling and simulation approaches. It uses the MBSE (Model-Based Systems Engineering) methodology to guide system design throughout the lifecycle. Students gain hands-on experience with SysML to formalize some aspects of the requirements, functions, and structures. Complementary paradigms are also explored, including multi-agent modeling (NetLogo) for emergent behaviors and cyber-physical system modeling (OpenModelica) for simulating physical components and their interactions with control systems. An introduction to the FMI standard covers co-simulation of heterogeneous models. Finally, a presentation from AFIS and a professional testimonial illustrate the role of systems engineers in industry and the practical use of digital twins.

Learning outcomes: By the end of this course, students will be able to formulate the relevant questions for system design, particularly regarding modeling aspects, and outline possible solutions.

Evaluation methods: Multiple-choice questions and case study (1.5 hours)

Evaluated skills:

- Systems Analysis

CM:

1. Introduction à l'ingénierie système (définitions, historique, motivations, concepts système) (2.0 h)
2. MBSE (définitions, évolution, cycles de vie, interfaces, processus, exigences, V&V (2.0 h)
3. Introduction à SysML (1.0 h)
4. modélisation et simulation à base d'agents (1.0 h)
5. modélisation de systèmes cyber-physiques et co-simulation (1.0 h)
6. AFIS (2.0 h)
7. Jumeaux Numérique (2.0 h)

TP:

1. familiarisation avec un logiciel de modélisation SysML, mise en évidence des liens entre diagrammes (3.0 h)
2. modélisation et simulation à base d'agents (3.0 h)
3. modélisation de systèmes cyber-physiques et co-simulation (3.0 h)

Sport S08

Course supervisor: Hervé Frezza-Buet

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

SportS08 *back*

TD:

1. Cours de sport (21.0 h)

Engineering internship

Course supervisor: Hervé Frezza-Buet, Damien Rontani

SPM-STA-002 *back*

Evaluated skills:
- Physical Engineering Design
- Physical Modeling
- Data Processing
- Systems Analysis
- Business Intelligence

Foreign Languages and Culture 1

Course supervisor: Elisabeth Leuba

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

LV1S08 *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

TD:

1. Cours (21.0 h)

Foreign Languages and Culture 2

Course supervisor: Beate Mansanti

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

LV2S08 *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

TD:

1. Cours (21.0 h)