

PHYS-490

**Elective project nuclear engineering**

Profs divers \*

Cursus	Sem.	Type
Nuclear engineering	MA1, MA2, MA3, MA4	Opt.

Language	English
Credits	8
Session	Winter, Summer
Semester	Fall
Exam	During the semester
Workload	240h
Weeks	14
<b>Hours</b>	<b>8 weekly</b>
Project	8 weekly
<b>Number of positions</b>	

**Summary**

The elective project is designed to train the students in the solution of specific engineering problems related to nuclear technology. This makes use of the technical and social skills acquired during the master's program.

**Content**

The elective project has the purpose to train the students in the solution of specific engineering problems related to nuclear technology. This makes use of the technical and social skills acquired during the master's program. Tutors propose the subject of the project, elaborate the project plan, and define the roadmap together with their students, as well as monitor the overall execution.

It can be done during the first 3 semesters at EPFL, ETHZ or PSI.

**Learning Outcomes**

By the end of the course, the student must be able to:

- Analyze a technical problem

**Transversal skills**

- Write a scientific or technical report.

**Assessment methods**

Written project report and oral presentation

ME-409

**Energy conversion and renewable energy**

Maréchal François, Nguyen Tuong-Van

Cursus	Sem.	Type
Electrical and Electronical Engineering	MA1, MA3	Opt.
Energy Science and Technology	MA1, MA3	Obl.
Energy minor	H	Opt.
Environmental Sciences and Engineering	MA1, MA3	Opt.
Minor in Engineering for sustainability	H	Opt.
Nuclear engineering	MA1	Opt.

Language	English
Credits	4
Session	Winter
Semester	Fall
Exam	Written
Workload	120h
Weeks	14
<b>Hours</b>	<b>4 weekly</b>
Lecture	2 weekly
Exercises	1 weekly
Project	1 weekly
<b>Number of positions</b>	

**Summary**

This course presents an overview of (i) the current energy system and uses (ii) the main principles of conventional and renewable energy technologies and (iii) the most important parameters that define their efficiency, costs and environmental impacts.

**Content**

The course gives an **overview** of:

- **Energy systems and uses**
- **Thermodynamic, economic and environmental principles** relevant for energy conversion systems (energy and exergy efficiencies, levelised cost of energy, emission factors)
- **Power cycles** (Rankine, Brayton and combined cycles)
- **Thermal power plants** (coal, natural gas and nuclear)
- **Carbon capture, storage and use**
- **Heat pumps and Geothermal**
- **Wind and Hydro**
- **Solar (PV and Thermal)**
- **Biomass**
- **Energy storage**
- **Fuel cells**

Focus is on the presentation of the current energy system and uses (electricity, heat and mobility) and of the main conversion technologies (thermodynamics and processes) to satisfy our energy demands. The course does **not** go in details in the physics of each technology. The first half of the course is on the presentation of the **energy system, thermodynamics and conventional power sources**, and the other half on the **main renewable sources**. The **goal** is therefore (i) to describe the relation between the energy system and our demands, (ii) to explain the principles of each energy conversion technology and resources and assess their costs and impacts, (iii) assess their role in future energy systems.

**Keywords**

Energy system ; Energy conversion ; Fossil and renewable sources

**Learning Prerequisites****Required courses**

Physics I  
Physics II

### Recommended courses

This course is **recommended** to master students in their **first year** - as it presents different topics covered in more details in other courses, it is **NOT recommended** to take it in the second year if possible.

### Important concepts to start the course

- Thermodynamics (conservation laws - 1st and 2nd principles)
- Conservation principles (energy, mass, momentum)

### Learning Outcomes

By the end of the course, the student must be able to:

- Model energy conversion systems and industrial processes
- Draw the energy balances of an energy conversion system
- Elaborate energy conversion scenarios
- Describe the principles and limitations of the main energy conversion technologies
- Explain the efficiency and the main emission sources of energy conversion processes
- Quantify the efficiency and the main emission sources of energy conversion processes
- Compare energy conversion systems
- Describe Describe and explain the main thermodynamic cycles E5
- Explain Explain and apply the concepts of thermodynamic efficiency E6
- Explain Explain the principles and limitations of the main energy conversion technologies E7
- Characterize Characterize fossil and renewable energy resources and their corresponding conversion technologies E8
- Explain Explain and calculate the main emission sources of energy conversion processes E23
- Explain Understand the challenges related to energy: resources, energy services, economic and environmental impacts E9
- Compare energy conversion systems (efficiency, economics and impacts)
- Describe the main thermodynamic cycles
- Apply the concepts of thermodynamic efficiencies
- Model energy conversion systems and industrial processes
- Explain the main principles and limitations of energy conversion and storage technologies
- Characterize fossil and renewable energy resources and their corresponding conversion technologies
- Assess / Evaluate the challenges related to energy: resources, energy services, economic and environmental impacts
- Derive the energy balances of an energy conversion system

### Transversal skills

- Use a work methodology appropriate to the task.
- Demonstrate the capacity for critical thinking
- Write a scientific or technical report.
- Access and evaluate appropriate sources of information.
- Identify the different roles that are involved in well-functioning teams and assume different roles, including leadership roles.

### Teaching methods

Ex-cathedra lectures of 2 hours per week, completed by 1-2 hours of exercise/project sessions with the teaching assistants

### Expected student activities

- Active participation to the **lecture sessions**
- **Exercices** consisting of theory questions and case studies, for the exam preparation
- **Mini-project** consisting in proposing an energy transition pathway for Switzerland

### Assessment methods

- Written exam at the end of the semester
- Final project report and milestones

### Supervision

Office hours	Yes
Assistants	Yes
Forum	Yes

### Resources

#### Notes/Handbook

The course material consists of the following:

- Course compendium (lectures, exercises, solutions, project and former exams with corrections), available as a .pdf and on a dedicated website
- Slides and Pre-recorded videos, available on Moodle and on a SWITCHtube channel

Note that the course compendium and the slides/videos present the same content, the main difference lies in the addition of examples and further details in the coursebook in case of interest or need of explanations. This is done so that the interested student can choose the most suitable material and follow the course in case of conflict with other courses.

#### Websites

- <http://moodle.epfl.ch>
- <http://www.energyscope.ch>

#### Moodle Link

- <https://go.epfl.ch/ME-409>

#### Videos

- <https://tube.switch.ch/channels/90cbb52f>

PHYS-405

**Experimental methods in physics**

Cantoni Marco, Dwir Benjamin

Cursus	Sem.	Type
Ing.-phys	MA1, MA3	Opt.
Nuclear engineering	MA1	Opt.
Physicien	MA1, MA3	Opt.

Language	English
Credits	3
Session	Winter
Semester	Fall
Exam	Oral
Workload	90h
Weeks	14
<b>Hours</b>	<b>3 weekly</b>
Lecture	2 weekly
Exercises	1 weekly
<b>Number of positions</b>	

**Summary**

The course's objectives are: Learning several advanced methods in experimental physics, and critical reading of experimental papers.

**Content**

- **Noise and interference:** Their origins, their influence on experimental results, methods for noise and interference reduction
- **Scanning probe microscopy (SPM):** Principles of operation of the scanning tunneling microscope and atomic force microscope, Advanced scanning microscopy techniques, applications
- **Optical spectroscopies:** The elements of a modern spectroscopy system; different methods of spectral dispersion and their advantages, optical detectors. Related methods: raman spectroscopy, cathodoluminescence.
- **Electron microscopy:** Transmission and scanning microscopes, their principles of operation, observation techniques, uses ...
- **Structural characterization:** RX, electron diffraction, ...

**Keywords**

Noise, Scanning probe microscopy, optical spectroscopy, transmission electron microscopy, scanning electron microscopy, electron diffraction, X-ray diffraction

**Learning Prerequisites****Recommended courses**

Basis courses in physics

**Important concepts to start the course**

fundamentals of optics, electromagnetics, atomic and solid-state physics

**Learning Outcomes**

By the end of the course, the student must be able to:

- Integrate the notions of critical reading of articles
- Assess / Evaluate scientific articles, their quality and defaults
- Interpret knowledge of several specific experimental methods

**Transversal skills**

- Communicate effectively, being understood, including across different languages and cultures.
- Give feedback (critique) in an appropriate fashion.
- Demonstrate the capacity for critical thinking
- Access and evaluate appropriate sources of information.
- Make an oral presentation.
- Summarize an article or a technical report.

### Teaching methods

- Ex cathedra lectures on specific experimental techniques
- Students' presentations of scientific articles

### Expected student activities

Participation in class is encouraged.

Students are expected to give a short presentation of a scientific article.

### Assessment methods

oral exam (100%)

### Supervision

Others                      Moodle

### Resources

#### Notes/Handbook

All is put on the Moodle site

#### Moodle Link

- <https://go.epfl.ch/PHYS-405>

ME-453

**Hydraulic turbomachines**

Vagnoni Elena

Cursus	Sem.	Type
Energy Science and Technology	MA1, MA3	Obl.
Energy minor	H	Opt.
Mechanical engineering minor	H	Opt.
Mechanical engineering	MA1, MA3	Opt.
Mechanics		Opt.
Nuclear engineering	MA1	Opt.

Language	English
Credits	4
Session	Winter
Semester	Fall
Exam	Written
Workload	120h
Weeks	14
<b>Hours</b>	<b>4 weekly</b>
Lecture	3 weekly
Exercises	1 weekly
<b>Number of positions</b>	

**Summary**

Master lecture on Hydraulic Turbomachines: impulse and reaction turbines, pumps and pump-turbines.

**Content**

- Turbomachine equations, mechanical power balance in a hydraulic machines, moment of momentum balance applied to the runner/impeller, generalized Euler equation.
- Hydraulic characteristic of a reaction turbine, a Pelton turbine and a pump, losses and efficiencies of a turbomachine, real hydraulic characteristics.
- Similitude laws, non dimensional coefficients, reduced scale model testing, scale effects.
- Cavitation, hydraulic machine setting, operating range, adaptation to the piping system, operating stability, start stop transient operation, runaway.
- Reaction turbine design: general procedure, general project layout, design of a Francis runner, design of the spiral casing and the distributor, draft tube role, CFD validation of the design, design fix, reduced scale model experimental validation.
- Pelton turbine design: general procedure, project layout, injector design, bucket design, mechanical problems.
- Centrifugal pump design: general architecture, energetic loss model in the diffuser and/or the volute, volute design, operating stability.

**Learning Prerequisites****Recommended courses**

Incompressible Fluids Mechanics  
Introduction to turbomachines

**Learning Outcomes**

By the end of the course, the student must be able to:

- Formulate the operating point of a hydraulic turbomachine
- Specify a type of hydraulic turbine
- Sketch the layout of a hydraulic turbomachine
- Select appropriately the dimensions of a hydraulic turbomachine

**Transversal skills**

- Use a work methodology appropriate to the task.
- Communicate effectively with professionals from other disciplines.
- Assess one's own level of skill acquisition, and plan their on-going learning goals.

### Teaching methods

ex cathedra lectures with working case studies

### Expected student activities

attendance at lectures completing exercises and reading written material

### Assessment methods

written exam

### Resources

#### Bibliography

P. HENRY: Turbomachines hydrauliques - Choix illustré de réalisation marquantes, PPUR, Lausanne, 1992.

Franc, Avellan et al., Cavitation, EDP Grenoble, 1994

Handout and Scientific Litterature from LMH, Industry, International Association

#### Ressources en bibliothèque

- [Cavitation / Franc](#)
- [Turbomachines hydrauliques / Henry](#)

#### Notes/Handbook

slides handout Handbook

#### Moodle Link

- <https://go.epfl.ch/ME-453>

### Prerequisite for

Cavitation, Hydroacoustic, Master Project



MICRO-511

**Image processing I**

Unser Michaël, Van De Ville Dimitri

Cursus	Sem.	Type
Biocomputing minor	H	Opt.
Computational Neurosciences minor	H	Opt.
Computational science and Engineering	MA1, MA3	Opt.
Computer science	MA1, MA3	Opt.
Cybersecurity	MA1, MA3	Opt.
Digital Humanities	MA1, MA3	Opt.
Environmental Sciences and Engineering	MA1, MA3	Opt.
Life Sciences Engineering	MA1, MA3	Opt.
Microtechnics	MA1, MA3	Opt.
Minor in Imaging	H	Opt.
Minor in life sciences engineering	H	Opt.
Neuro-X minor	H	Opt.
Neuro-X	MA1, MA3	Opt.
Neuroprosthetics minor	H	Opt.
Nuclear engineering	MA1	Opt.
Photonics minor	H	Opt.
Robotics, Control and Intelligent Systems		Opt.
Robotics	MA1, MA3	Opt.
SC master EPFL	MA1, MA3	Opt.

Language	English
Credits	3
Session	Winter
Semester	Fall
Exam	Written
Workload	90h
Weeks	14
<b>Hours</b>	<b>3 weekly</b>
Lecture	3 weekly
<b>Number of positions</b>	

**Summary**

Introduction to the basic techniques of image processing. Introduction to the development of image-processing software and to prototyping using Jupyter notebooks. Application to real-world examples in industrial vision and biomedical imaging.

**Content**

- **Introduction.** Image processing versus image analysis. Applications. System components.
- **Characterization of continuous images.** Image classes. 2D Fourier transform. Shift-invariant systems.
- **Image acquisition.** Sampling theory. Acquisition systems. Histogram and simple statistics. Max-Lloyd quantization (K-means).
- **Characterization of discrete images and linear filtering.** z-transform. Convolution. Separability. FIR and IIR filters.
- **Morphological operators.** Binary morphology (opening, closing, etc.). Gray-level morphology.
- **Image-processing tasks.** Preprocessing. Matching and detection. Feature extraction. Segmentation.
- **Convolutional neural networks.** Basic components. Operator-based formalism. CNN in practice: denoising and segmentation.

**Learning Prerequisites****Required courses**

Signals and Systems I & II (or equivalent)

**Important concepts to start the course**

1-D signal processing: convolution, Fourier transform, z-transform

**Learning Outcomes**

By the end of the course, the student must be able to:

- Exploit the multidimensional Fourier transform
- Select appropriately Hilbert spaces and inner-products
- Optimize 2-D sampling to avoid aliasing
- Formalize convolution and optical systems
- Design digital filters in 2-D
- Analyze multidimensional linear shift-invariant systems
- Apply image-analysis techniques
- Construct image-processing software

**Transversal skills**

- Use a work methodology appropriate to the task.
- Manage priorities.
- Use both general and domain specific IT resources and tools

**Assessment methods**

- 70% final exam
- 30% IP labs during semester

**Resources****Moodle Link**

- <https://go.epfl.ch/MICRO-511>

PHYS-455

**Introduction to medical radiation physics**

Bochud François

Cursus	Sem.	Type
Nuclear engineering	MA1	Opt.

Language	English
Credits	4
Session	Winter
Semester	Fall
Exam	Written
Workload	120h
Weeks	14
<b>Hours</b>	<b>3 weekly</b>
Lecture	2 weekly
Exercises	1 weekly
<b>Number of positions</b>	

**Summary**

This course covers the physical principles underlying medical diagnostic imaging (radiography, fluoroscopy, CT, SPECT, PET, MRI), radiation therapy and radiopharmacy. The focus is not only on risk and dose to the patient and staff, but also on an objective description of the image quality.

**Content**

**Physics of radiography** x-ray device, x-ray spectra, main image receptors

**Image quality** main challenge, signal theory, decision theory

**Physics of radiation therapy** epidemiological data about cancer, general workflow, beam production and characterization, dose calculation, dose distribution, high-level treatment techniques

**Risk and radiation** effects, acute and chronic risks, psychological aspects, communication about radiation risk

**Radiopharmaceutical products** types of radiopharmaceuticals in nuclear medicine, lab infrastructure, labeling approaches, thin layer chromatography

**Physics of radioscopy** radiography and fluoroscopy units, challenges of radiation protection, dose indicators

**Physics of computer tomography (CT)** principle of CT image acquisition, image quality, DECT

**Physics of resonance magnetic imaging (MRI)** MRI acquisition, proton density, localization of the signal

**Physics of single-photon emission computed tomography (SPECT)** gamma camera imaging, resolution and sensitivity, quantitative imaging

**Physics of positron emission tomography (PET)** coincidence detection, time-of-flight systems, resolution and sensitivity, quantitative imaging

**Dose to the patient** general method, dose estimation in radiodiagnostic, dose estimation in internal contamination

**Receiver operating characteristics (ROC)** meaning of a ROC curve, detection experiment, performance communication

**Model observers in medical imaging and human vision** objective image quality, ideal and anthropomorphic observers, visual pathway, perception of a signal

**Keywords**

medical imaging, medical radiation

**Learning Prerequisites****Recommended courses**

This course has many synergies with the Radiation biology, protection and applications course where the basics of radiation physics and some aspects of radiation protection are very useful to follow the present course.

**Teaching methods**

Ex-cathedra with integrated individual exercises

## Assessment methods

Written exam

## Resources

### Bibliography

Course in general

- William R. Hendee and E. Russell Ritenour, "Medical Imaging Physics", Wiley-Liss, 4th edition, 2002
- The Essential Physics of Medical Imaging, Third Edition, Jerrold T. Bushberg

### Références suggérées par la bibliothèque

- [The Essential Physics of Medical Imaging, Third Edition, Jerrold T. Bushberg](#)
- [William R. Hendee and E. Russell Ritenour, "Medical Imaging Physics"](#)

### Moodle Link

- <https://go.epfl.ch/PHYS-455>

PHYS-448

**Introduction to particle accelerators**

Seidel Mike

Cursus	Sem.	Type
Ing.-phys	MA1, MA3	Opt.
Nuclear engineering	MA1	Opt.
Physicien	MA1, MA3	Opt.

Language	English
Credits	4
Session	Winter
Semester	Fall
Exam	Written
Workload	120h
Weeks	14
<b>Hours</b>	<b>4 weekly</b>
Lecture	2 weekly
Exercises	2 weekly
<b>Number of positions</b>	

**Summary**

The course presents basic physics ideas underlying the workings of modern accelerators. We will examine key features and limitations of these machines as used in accelerator driven sciences like high energy physics, materials and life sciences.

**Content**

Overview, history and fundamentals  
 Transverse particle dynamics (linear and nonlinear)  
 Longitudinal particle dynamics  
 Synchrotron radiation and related dynamics  
 Linear and circular accelerators  
 Acceleration and RF-technology  
 Beam diagnostics  
 Accelerator magnets  
 Medical application of accelerators  
 Future projects

**Learning Outcomes**

By the end of the course, the student must be able to:

- Design basic linear and non-linear charged particles optics
- Elaborate basic ideas of physics of accelerators
- Use a computer code for optics design
- Optimize accelerator design for a given application
- Estimate main beam parameters of a given accelerator

**Transversal skills**

- Communicate effectively with professionals from other disciplines.
- Use both general and domain specific IT resources and tools

**Expected student activities**

working on weekly problems, submitting the solutions and participation in the computer tutorials

**Assessment methods**

written exam

## Resources

### Moodle Link

- <https://go.epfl.ch/PHYS-448>

ME-454

**Modelling and optimization of energy systems**

Maréchal François

Cursus	Sem.	Type
Energy Science and Technology	MA1, MA3	Opt.
Energy minor	H	Opt.
Ing.-chim.	MA1, MA3	Opt.
Mechanical engineering minor	H	Opt.
Mechanical engineering	MA1, MA3	Opt.
Minor in Integrated Design, Architecture and Sustainability	H	Opt.
Nuclear engineering	MA1	Opt.
Systems Engineering minor	H	Opt.

Language	English
Credits	4
Session	Winter
Semester	Fall
Exam	Oral
Workload	120h
Weeks	14
<b>Hours</b>	<b>4 weekly</b>
Lecture	2 weekly
Exercises	2 weekly
<b>Number of positions</b>	

**Summary**

The goal of the lecture is to present and apply techniques for the modelling and the thermo-economic optimisation of industrial process and energy systems. The lecture covers the problem statement, the solving methods for the simulation and the single and multi-objective optimisation problems.

**Content**

- Concepts of Computer Aided Process System Engineering methods to tackle the problems of energy conversion systems modelling and optimisation. The students will acquire a methodology to state the problem, identify the solving procedure, solve the problem and analyse the results;
- Definition of the basic system modelling concepts : state variables, energy and mass balances, simulation parameters and equations, degree of freedom analysis, different types of specifications, inequalities, objective functions;
- Energy systems equipments models;
- System models : flowsheets, degrees of freedom, sequential or simultaneous solving approach, numerical methods and their implications;
- Measurement data reconciliation and parameter identification;
- Calculating systems performances : operating cost, efficiency, environmental impact, investments, thermo-economic and environmental performances;
- Stating and solving optimization problems : decision variables, objective functions and constraints, solving strategies, numerical methods and their implications;
- Realization of a case study.

**Keywords**

Process system engineering, Process simulation, optimization

**Learning Prerequisites****Recommended courses****Prerequisite skills**

- Master the concepts of mass, energy, and momentum balance, E1 (Thermodynamique et énergétique I)
- Compute the thermodynamic properties of a fluid, E2 (Thermodynamique et énergétique I)
- Master the concepts of heat and mass transfer, E3 (Heat and mass transfer)
- Understand the main thermodynamic cycles, E5 (Thermodynamique et énergétique I)
- Notion of optimization (Introduction à l'optimisation différentiable)

**Learning Outcomes**

By the end of the course, the student must be able to:

- Master the concepts of thermodynamic efficiency, E6
- Establish the flow diagram of an industrial process and calculate the corresponding energy and mass balance, E22
- Analyse the energy and exergy efficiency of industrial energy systems, E23
- Model, design and optimize energy conversion systems and industrial processes, E24
- Establish the flow diagram of an industrial process and calculate the corresponding energy and mass balance, E20
- Explain and apply the concepts of thermodynamic efficiency, E6
- Analyze the energy and exergy efficiency of industrial energy systems, E21
- Model, design and optimize energy conversion systems and industrial processes, E22

### Transversal skills

- Write a scientific or technical report.
- Make an oral presentation.
- Keep appropriate documentation for group meetings.
- Access and evaluate appropriate sources of information.

### Teaching methods

The course is organised as theoretical sessions and the resolution of a real case study to be realised by a student team coached by an assistant.

### Expected student activities

Participation to a team project and contribution to the report.  
Active participation to the lectures and mastering the theoretical concepts applied to solve the project.

### Assessment methods

An oral exam will concern the theory and its application in the case study.

### Resources

#### Bibliography

All the material can be downloaded from the moodle website (<http://moodle.epfl.ch/course/view.php?id=11>).  
Printed version of the lecture notes can be ordered.

#### Moodle Link

- <https://go.epfl.ch/ME-454>

#### Videos

- <http://www.klewel.com/conferences/epfl-energy-systems/>



PHYS-640

**Neutron and X-ray Scattering of Quantum Materials**

Fogh Ellen, Rønnow Henrik M., Schmitt Thorsten

Cursus	Sem.	Type
Ing.-phys	MA1, MA3	Opt.
Nuclear engineering	MA1	Opt.
Physicien	MA1, MA3	Opt.
Physics		Opt.

Language	English
Credits	4
Session	Winter
Semester	Fall
Exam	Oral
Workload	120h
Weeks	14
<b>Hours</b>	<b>4 weekly</b>
Lecture	2 weekly
Exercises	2 weekly
<b>Number of positions</b>	

**Frequency**

Every year

**Remark**

Next time: Fall

**Summary**

Neutron and X-ray scattering are some of the most powerful and versatile experimental methods to study the structure and dynamics of materials on the atomic scale. This course covers basic theory, instrumentation and scientific applications of these experimental methods.

**Content**

The application of neutron and X-ray scattering spans from crystalline matter to bio-materials and engineering, including fields like magnetism and superconductivity. Similar to the vast possibilities with X-rays at synchrotron facilities like the Swiss Light Source at the Paul Scherrer Institute (PSI) in Switzerland, the European Synchrotron Radiation Facility in Grenoble, neutron scattering is a large-scale-facility technique with neutron sources among others at PSI in Switzerland, the Institute Laue-Langevin in Grenoble and a new joint European Spallation Source under construction in Sweden. The course provides an introduction to the dynamic experimental techniques of neutron and X-ray scattering and covers the following aspects:

- 1) Theory of the neutron scattering cross section
- 2) Neutron sources and neutron instrumentation
- 3) Neutron imaging, neutron reflectivity and neutron small angle scattering
- 4) Neutron diffraction, crystal structures
- 5) Inelastic neutron scattering, phonons
- 6) Magnetic neutron scattering, magnetic structures
- 7) Inelastic magnetic neutron scattering, magnetic dynamics
- 8) Theory of the interaction between X-rays and matter
- 9) X-ray sources and X-ray instrumentation
- 10) X-ray absorption spectroscopy
- 11) X-ray emission spectroscopy and Resonant Inelastic X-ray Scattering (RIXS)
- 12) Resonant Elastic X-ray Scattering (REXS)
- 13) Inelastic X-ray Scattering
- 14) Time resolved pump-probe X-ray spectroscopy

The course contains lectures and exercise sessions. Exercise sessions will contain derivation of relevant formulas, Monte-Carlo simulation of neutron scattering experiments, and discussions of representative scientific articles using X-ray and neutron scattering techniques. The course includes performing a real neutron or X-ray experiment and a tour of the large-scale experimental research facilities at the PSI.

**Keywords**

Neutron Scattering, X-ray scattering, X-ray spectroscopy, diffraction, crystal structures, lattice vibrations, phonons, magnetism, spin waves, magnons, neutron imaging

## Learning Prerequisites

### Required courses

Solid State Physics 1 and 2, basic quantum mechanics and basic atomic physics.

## Learning Outcomes

By the end of the course, the student must be able to:

- predict and interpret neutron and X-ray scattering experiments.
- Read and evaluate articles containing neutron and X-ray scattering results

## Resources

### Bibliography

"Elements of Modern X-ray Physics" by Des McMorrow and Jens Als-Nielsen (2nd edition)

"Neutron scattering Theory, Instrumentation and Simulation", lecture notes by Kim Lefmann

Relevant scientific articles

### Websites

- [http://Lab web page: lqm.epfl.ch](http://Lab%20web%20page%20lqm.epfl.ch)

PHYS-445

**Nuclear fusion and plasma physics**

Fasoli Ambrogio

Cursus	Sem.	Type
Auditeurs en ligne	H	Opt.
Energy Science and Technology	MA1, MA3	Opt.
Ing.-phys	MA1, MA3	Opt.
Nuclear engineering	MA1	Opt.
Physicien	MA1, MA3	Opt.

Language	English
Credits	4
Session	Winter
Semester	Fall
Exam	Oral
Workload	120h
Weeks	14
<b>Hours</b>	<b>4 weekly</b>
Lecture	2 weekly
Exercises	2 weekly
<b>Number of positions</b>	

**Summary**

The goal of the course is to provide the physics and technology basis for controlled fusion research, from the main elements of plasma physics to the reactor concepts.

**Content**

- 1) Basics of thermonuclear fusion
- 2) The plasma state and its collective effects
- 3) Charged particle motion and collisional effects
- 4) Fluid description of a plasma
- 5) Plasma equilibrium and stability
- 6) Magnetic confinement: Tokamak and Stellarator
- 7) Waves in plasma
- 8) Wave-particle interactions
- 9) Heating and non inductive current drive by radio frequency waves
- 10) Heating and non inductive current drive by neutral particle beams
- 11) Material science and technology: Low and high Temperature superconductor - Properties of material under irradiation
- 12) Some nuclear aspects of a fusion reactor: Tritium production
- 13) Licensing a fusion reactor: safety, nuclear waste
- 14) Inertial confinement

**Learning Prerequisites****Recommended courses**

Basicknowledge of electricity and magnetism, and of simple concepts of fluids

**Learning Outcomes**

By the end of the course, the student must be able to:

- Design the main elements of a fusion reactor
- Identify the main physics challenges on the way to fusion
- Identify the main technological challenges of fusion

**Teaching methods**

Ex cathedra and in-class exercises

**Assessment methods**

oral examen (100%)

## Resources

### Websites

- <https://spcnet.epfl.ch/nuclfus/>

### Moodle Link

- <https://go.epfl.ch/PHYS-445>

PHYS-461

**Nuclear interaction : from reactors to stars**

Rochman Dimitri

Cursus	Sem.	Type
Ing.-phys	MA1, MA3	Opt.
Nuclear engineering	MA1	Opt.
Physicien	MA1, MA3	Opt.

Language	English
Credits	4
Session	Winter
Semester	Fall
Exam	Written
Workload	120h
Weeks	14
<b>Hours</b>	<b>4 weekly</b>
Lecture	2 weekly
Exercises	2 weekly
<b>Number of positions</b>	

**Summary**

This course will present an overview of the nuclear interactions for neutrons on nuclei below a few hundreds of MeV. The aspect of so-called "nuclear data" will be presented from the perspective of experiments, compilation, calculation, evaluation, processing and applications.

**Content**

The following subjects will be presented:

- **Nuclear data needs:** It is important to understand if, and where, nuclear data are needed, why, which accuracy is required from the applications or industries. Such needs concerns a large range of applications: energy, medical, waste and astrophysics. Each of these fields requires different knowledge on nuclear interactions with, either with neutrons, or protons, or both.
- **Theoretical background:** Many of the needs are covered by experimental knowledge, but not all. Some reactions cannot be easily measured, or are simply out of range with current technologies (for instance for with short-lived isotopes). What can we do in this case ? Part of the answer relies on theoretical understanding and the prediction power of current models (with their shortcoming). We will then explore (not in details) some of the important models, their range of applications, and what to do when nothing is known.
- **Measurement facilities:** The current knowledge of nuclear interactions, cross sections and uncertainties is based on measurements. In many instances, measurements are necessary due to the lack of prediction power for models. We will see the existing facilities, their advantages and drawback. We will also visit the installation worldwide, with a view on the future needs.
- **Evaluation:** Once quantities have been measured or calculated, they need to be presented to potential users. This step is called "evaluation". The outcome of the process is "what the users will see". It covers compiling measurements, combining them with theoretical predictions, formatting, and processing in forms that users need. We will go through these steps, and you will globally understand the importance of these steps.
- **Applications:** finally, we will see how these nuclear data are used. What are the applications, what are the needs, and how users can propose feedback to influence new measurements, or new calculations.

**Learning Outcomes**

By the end of the course, the student must be able to:

- Use applications codes

**Assessment methods**

written exam

MATH-468

**Numerics for fluids, structures & electromagnetics**

Cursus	Sem.	Type
Computational science and Engineering	MA1, MA3	Opt.
Ing.-math	MA1, MA3	Opt.
Mathématicien	MA1, MA3	Opt.
Nuclear engineering	MA1	Opt.

Language	English
Credits	5
Session	Winter
Semester	Fall
Exam	Oral
Workload	150h
Weeks	14
<b>Hours</b>	<b>4 weekly</b>
Lecture	2 weekly
Exercises	2 weekly
<b>Number of positions</b>	

**Remark**

Pas donné en 2023-24. Cours donné tous les deux ans.

**Summary**

Cours donné en alternance tous les deux ans

**Content****Learning Outcomes**

By the end of the course, the student must be able to:

**Transversal skills**

- Make an oral presentation.

**Assessment methods**

Oral

**Supervision**

Forum                      Yes

**Resources****Moodle Link**

- <https://go.epfl.ch/MATH-468>

**Videos**

- <http://Recording of the lectures will be provided after each lecture.>

PHYS-443

**Physics of nuclear reactors**

Hursin Mathieu

Cursus	Sem.	Type
Nuclear engineering	MA1	Obl.

Language	English
Credits	6
Session	Winter
Semester	Fall
Exam	Oral
Workload	180h
Weeks	14
<b>Hours</b>	<b>6 weekly</b>
Lecture	4 weekly
Exercises	2 weekly
<b>Number of positions</b>	

**Summary**

In this course, one acquires an understanding of the basic neutronics interactions occurring in a nuclear fission reactor as well as the conditions for establishing and controlling a nuclear chain reaction.

**Content**

- **Brief review of nuclear physics**

- Historical: Constitution of the nucleus and discovery of the neutron
- Nuclear reactions and radioactivity
- Cross sections
- Differences between fusion and fission.

- **Nuclear fission**

- Characteristics - Nuclear fuel - Introductory elements of neutronics.
- Fissile and fertile materials.

- **Element of reactor design**

- flux and heat source distribution; properties of different coolants and technological consequences

- **LWR reactors technology**

- overview of the functional scheme of PWR and BWRs; fuel elements; compensation of excess reactivity in PWRs and BWRs (boron, etc.)

- **Neutron diffusion and slowing down**

- Monoenergetic neutrons - Angular and scalar flux
- Diffusion theory as simplified case of transport theory - Neutron slowing down through elastic scattering.

- **Multiplying media (reactors)**

- Multiplication factors - Criticality condition in simple cases.
- Thermal reactors - Neutron spectra - Multizone reactors - Multigroup theory and general criticality condition - Heterogeneous reactors.

- **Reactor kinetics**

- Point reactor model: prompt and delayed transients - Practical applications.

- **Reactivity variations and control**

- Short, medium and long term reactivity changes. Different means of control.

- **Advanced reactor designs**

- Breeding and transmutation; introduction into Gen-IV reactors

**Learning Outcomes**

By the end of the course, the student must be able to:

- Elaborate on neutron diffusion equation
- Formulate approximations to solving the diffusion equation for simple systems
- Classify nuclear reaction cross sections
- Develop for a nuclear reactor

### Transversal skills

- Access and evaluate appropriate sources of information.
- Collect data.
- Use both general and domain specific IT resources and tools
- Write a scientific or technical report.

### Teaching methods

Lectures, numerical exercises

### Assessment methods

oral exam (50%)  
group project (50%)

### Resources

#### Moodle Link

- <https://go.epfl.ch/PHYS-443>



PHYS-423

**Plasma I**

Theiler Christian Gabriel

Cursus	Sem.	Type
Energy minor	H	Opt.
Ing.-phys	MA1, MA3	Opt.
Nuclear engineering	MA1	Opt.
Physicien	MA1, MA3	Opt.

Language	English
Credits	6
Session	Winter
Semester	Fall
Exam	Oral
Workload	180h
Weeks	14
<b>Hours</b>	<b>5 weekly</b>
Lecture	2 weekly
Exercises	3 weekly
<b>Number of positions</b>	

**Summary**

Following an introduction of the main plasma properties, the fundamental concepts of the fluid and kinetic theory of plasmas are introduced. Applications concerning laboratory, space, and astrophysical plasmas are discussed throughout the course.

**Content****I Collisional and relaxation phenomena**

- Inelastic collisions: ionization and recombination, degree of ionization
- Elastic collisions: Coulomb collisions
- Isotropisation and thermalisation
- Plasma resistivity and the runaway regime

**II Transport in plasmas**

- Random walk and diffusion
- Ambipolar and cross-field diffusion
- Energy and particle confinement

**III Waves in cold magnetized plasma**

- Dielectric tensor
- Resonances and cut-offs
- Parallel and perpendicular propagation

**IV Wave-particle interaction and kinetic description of waves in hot un-magnetized plasmas**

- The Vlasov-Maxwell model
- Resonant wave-particle interaction and Landau damping
- Stability criteria and streaming instabilities
- Langmuir and ion-acoustic waves and instabilities

**V Waves in hot magnetized plasmas****VI Examples of nonlinear effects****Learning Prerequisites****Recommended courses**

PHYS-324: Classical Electrodynamics, PHYS-325: Introduction to Plasma Physics

**Learning Outcomes**

By the end of the course, the student must be able to:

- Manipulate the fundamental elements of the plasma fluid and kinetic theory

**Teaching methods**

Ex cathedra and exercises in class

### **Assessment methods**

oral exam

### **Resources**

#### **Moodle Link**

- <https://go.epfl.ch/PHYS-423>

PHYS-451

**Radiation and reactor experiments**

Hursin Mathieu, Lamirand Vincent, Pakari Oskari Ville

Cursus	Sem.	Type
Nuclear engineering	MA1	Obl.

Language	English
Credits	6
Withdrawal Session	Unauthorized Winter
Semester	Fall
Exam	During the semester
Workload	180h
Weeks	14
<b>Hours</b>	<b>4 weekly</b>
Practical work	4 weekly
<b>Number of positions</b>	<b>30</b>

**Summary**

The reactor experiments course aims to introduce the students to radiation detection techniques and nuclear reactor experiments. The core of the course is the unique opportunity to conduct reactor experiments, as the control rod calibration, and approach to critical.

**Content**

- Radiation detector systems, alpha and beta particles
- Radiation detector systems, gamma spectroscopy
- Introduction to neutron detectors (He-3, BF<sub>3</sub>)
- Slowing-down area (Fermi age) of Pu-Be neutrons in H<sub>2</sub>O
- Approach-to-critical experiments
- Buckling measurements
- Reactor power calibration
- Control rod calibration

**Learning Outcomes**

By the end of the course, the student must be able to:

- Apply measurement techniques for alpha, beta, gamma and neutron radiation detection.
- Carry out measurement techniques to obtain CROCUS reactor characteristics.
- Conduct both reactor power and control rod calibration.
- Plan the critical experiment.

**Teaching methods**

Instructions and supervision during lab work

**Assessment methods**

reports and oral examination during the semester

**Resources****Bibliography**

Handouts will be distributed

- James E. Martin, "Physics for Radiation Protection", Wiley-VCH (2nd edition, 2006)
- F.M. Khan, "The Physics of Radiation Therapy", Lippincott, Williams & Wilkins, (4th edition, 2010)
- G.C. Lowenthal, P.L. Airey, "Practical Applications of Radioactivity and Nuclear Reactions", Cambridge University Press (2001)
- K.H. Lieser, "Nuclear and Radiochemistry", Wiley-VCH (2nd edition, 2001)

**Moodle Link**

- <https://go.epfl.ch/PHYS-451>

PHYS-450

**Radiation biology, protection and applications**

Damet Jerome, Grilj Veljko, Pakari Oskari Ville

Cursus	Sem.	Type
Ing.-phys	MA1, MA3	Opt.
Nuclear engineering	MA1	Obl.
Physicien	MA1, MA3	Opt.

Language	English
Credits	4
Session	Winter
Semester	Fall
Exam	Written
Workload	120h
Weeks	14
<b>Hours</b>	<b>3 weekly</b>
Lecture	2 weekly
Exercises	1 weekly
<b>Number of positions</b>	

**Summary**

This is an introductory course in radiation physics that aims at providing students with a foundation in radiation protection and with information about the main applications of radioactive sources/substances in the industry. The course includes presentations, lecture notes and problem sets.

**Content**

- Radioactivity and interactions of ionising radiation in matter
- Health effects of ionising radiation
- Dosimetry and population exposure
- Space radiation dosimetry
- Radioisotope production using reactors and accelerators
- Industrial applications: radiation gauges, tracer techniques, radioisotope batteries, radiation imaging, radiography, etc.
- Applications in research: dating by nuclear methods, applications in environmental and life sciences, etc.

**Learning Outcomes**

By the end of the course, the student must be able to:

- Explain the origin of ionising radiation
- Explain interactions of ionising radiation in matter.
- Explain biological/health effects of the ionising radiation
- Explain the principles of dosimetry
- Explain exposure to the general population and cite exposure levels
- Explain the principles of radiation protection, cite the dose limits
- Describe the protection means for external and internal exposure
- Explain the use of radiation in industrial and research applications.
- Design appropriate radiation shielding for a given source or application

**Assessment methods**

Written, Multiple Choice Question exam

**Resources**

## **Bibliography**

Handouts will be distributed

- James E. Martin, "Physics for Radiation Protection", Wiley-VCH (2nd edition, 2006)
- G.C. Lowenthal, P.L. Airey, "Practical Applications of Radioactivity and Nuclear Reactions", Cambridge University Press (2001)
- K.H. Lieser, "Nuclear and Radiochemistry", Wiley-VCH (2nd edition, 2001)

## **Ressources en bibliothèque**

- [Physics for Radiation Protection / Martin](#)
- [Nuclear and Radiochemistry / Lieser](#)
- [Practical Applications of Radioactivity and Nuclear Reactions / Lowenthal](#)

## **Moodle Link**

- <https://go.epfl.ch/PHYS-450>

PHYS-452

**Radiation detection**

Lamirand Vincent

Cursus	Sem.	Type
Ing.-phys	MA1, MA3	Opt.
Nuclear engineering	MA1	Opt.
Physicien	MA1, MA3	Opt.

Language	English
Credits	3
Session	Winter
Semester	Fall
Exam	Oral
Workload	90h
Weeks	14
<b>Hours</b>	<b>3 weekly</b>
Lecture	2 weekly
Exercises	1 weekly
<b>Number of positions</b>	

**Summary**

The course presents the detection of ionizing radiation in the keV and MeV energy ranges. Physical processes of radiation/matter interaction are introduced. All steps of detection are covered, as well as detectors, instrumentations and measurements methods commonly used in the nuclear field.

**Content**

- **Interaction of radiation with matter at low energies:** X-rays/gammas, charged particles and neutrons up to MeV range, ionisation, nuclear cross sections.
- **Characteristics and types of detectors:** gas detectors, semiconductor detectors, scintillators and optical fibers, fission chambers, meshed and pixel detectors
- **Signal processing and analysis:** types of electronics, signal collection and amplification, particle discrimination, spatial and time resolution
- **Nuclear instrumentation and measurements:** principle of measurements, spectrometry, common detection instrumentations, applications in nuclear engineering and R&D.

**Keywords**

radiation detection; radiation-matter interaction; ionizing radiation; detector; signal processing; nuclear instrumentation; measurement methods

**Learning Outcomes**

By the end of the course, the student must be able to:

- Explain interaction processes of ionising radiation and matter
- Describe the production of a detection signal and its processing
- Explain the operation of all types of commonly used detectors
- Assess / Evaluate the detection system and method required for a specific measurement

**Transversal skills**

- Communicate effectively with professionals from other disciplines.

**Teaching methods**

Lectures, exercises, presentations, practice.

**Expected student activities**

Attendance at lectures and exercises, short presentations.

### Assessment methods

Oral exam

### Supervision

Assistants                      Yes

### Resources

#### Bibliography

Radiation detection and measurement, Glenn F. Knoll. Wiley 2010  
Practical Gamma-Ray Spectrometry, Gordon R. Gilmore, Wiley & Sons 2008

#### Ressources en bibliothèque

- [Radiation detection and measurement, Glenn F. Knoll](#)
- [Practical Gamma-Ray Spectrometry, Gordon R. Gilmore](#)

#### Moodle Link

- <https://go.epfl.ch/PHYS-452>



ETH-590

**Semester Project Nuclear Engineering**

Profs divers \*

<b>Cursus</b>	<b>Sem.</b>	<b>Type</b>
Nuclear engineering	MA3	Obl.

Language	English
Credits	8
Session	Winter
Semester	Fall
Exam	During the semester
Workload	240h
Weeks	14
<b>Hours</b>	<b>8 weekly</b>
Project	8 weekly
<b>Number of positions</b>	

**Summary**

The semester project is designed to train the students in the solution of specific engineering problems. This makes use of the technical and social skills acquired during the master's programme.

**Content**

The semester project is designed to train the students in the solution of specific engineering problems. This makes use of the technical and social skills acquired during the master's program. Tutors propose the subject of the project, elaborate the project plan, and define the roadmap together with their students, as well as monitor the overall execution.

**Learning Outcomes**

By the end of the course, the student must be able to:

- Analyze a technical problem

**Transversal skills**

- Write a scientific or technical report.

PHYS-595

**Stage d'ingénierie (master en Génie nucléaire)**

Profs divers \*

Cursus	Sem.	Type
Génie nucléaire	MA2, MA3, MA4	Obl.

Langue	
Crédits	8
Session	Hiver, Eté
Semestre	Printemps
Examen	Pendant le semestre
Charge	240h
Semaines	14
Projet	8 hebdo
<b>Nombre de places</b>	

**Résumé**

The main objective of the 12-week internship is to expose master's students to the industrial work environment within the field of nuclear energy.

**Contenu**

The main objective of the 12-week internship is to expose master's students to the industrial work environment within the field of nuclear energy. During this period, students have the opportunity to be involved in on-going projects at the host institution.

**Acquis de formation**

A la fin de ce cours l'étudiant doit être capable de:

**Compétences transversales**

- Utiliser une méthodologie de travail appropriée, organiser un/son travail.
- Communiquer efficacement et être compris y compris par des personnes de langues et cultures différentes.

**Méthode d'évaluation**

an oral presentation could be asked by the company, not compulsory