PHYS-490

# Elective project nuclear engineering

Profs divers *

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

| | |
|---|---|
| Language of teaching | English |
| Credits | 8 |
| Session | Winter, Summer |
| Semester | Fall |
| Exam | During the semester |
| Workload | 240h |
| Weeks | 14 |
| **Hours** | **8 weekly** |
| Project | 8 weekly |
| **Number of positions** | |

## 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 programm.

## 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 |
|---|---|---|
| Civil Engineering | MA1, MA3 | Opt. |
| 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. |
| Managmt, dur et tech | MA3 | Opt. |
| Minor in Engineering for sustainability | H | Opt. |
| Nuclear engineering | MA1 | Opt. |

| | |
|---|---|
| Language of teaching | English |
| Credits | 4 |
| Session | Winter |
| Semester | Fall |
| Exam | Written |
| Workload | 120h |
| Weeks | 14 |
| **Hours** | **4 weekly** |
| Courses | 2 weekly |
| Exercises | 1 weekly |
| Project | 1 weekly |
| **Number of positions** | |

## 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

### 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:

- 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
- Explain principles and limitations of the main energy conversion technologies
- Characterize fossil and renewable energy resources and their corresponding conversion technologies
- Explain the challenges related to energy: resources, energy services, economic and environmental impacts

## Teaching methods

Ex-cathedra lectures of 2 hours per week, completed by 1 hour of exercises and 1 hour of project

## 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 (60%)
- Intermediate and final project report (40%)

## Supervision

| | |
|---|---|
| Office hours | No |
| 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.

### Moodle Link

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

### Videos

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

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 of teaching | English |
| Credits | 4 |
| Session | Winter |
| Semester | Fall |
| Exam | Written |
| Workload | 120h |
| Weeks | 14 |
| **Hours** | **4 weekly** |
| Courses | 3 weekly |
| Exercises | 1 weekly |
| **Number of positions** | |


### Summary

Master lecture on Hydraulic Turbomachines: operating principles and design of impulse and reaction turbines, industrial pumps and pump-turbines.


### Content

- Fundamental equations for turbomachines operation: mass conservation and specific energy equation for turbulent flows, 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.
- Similtude 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, 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.
- Sustainability in turbomachines manufacturing and operation

### 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 types and components of hydraulic turbine
- Design the layout of a hydraulic turbomachine

- Select appropriately the dimensions of a hydraulic turbomachine
- Describe The flow phenomena and instabilities in turbomachines

## 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 Scientifc Litterature from LMH, Industry, International Association

### Ressources en bibliothèque

- Find the references at the Library

### 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 |
|---|---|---|
| Computational and Quantitative Biology | | Opt. |
| Computational science and Engineering | MA1, MA3 | Opt. |
| Computational science and engineering minor | H | Opt. |
| Computer science | MA1, MA3 | Opt. |
| Cybersecurity | MA1, MA3 | Opt. |
| Data Science | 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. |
| 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 of teaching | English |
| Credits | 3 |
| Session | Winter |
| Semester | Fall |
| Exam | Written |
| Workload | 90h |
| Weeks | 14 |
| **Hours** | **3 weekly** |
| Courses | 2 weekly |
| Exercises | 1 weekly |
| **Number of positions** | |

## 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
- Elaborate morphological filters
- 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 of teaching | English |
| Credits | 4 |
| Session | Winter |
| Semester | Fall |
| Exam | Written |
| Workload | 120h |
| Weeks | 14 |
| **Hours** | **3 weekly** |
| Courses | 2 weekly |
| Exercises | 1 weekly |
| **Number of positions** | |


## Summary

This course covers the physical principles underlying medical diagnostic imaging (radiography, fluoroscopy, CT, SPECT, PET, MRI, US), 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

**Ionizing radiations in medical physics**

- Order the regions of the electromagnetic spectrum by increasing photon energy and explain the main types of interactions each region can have with water
- Explain the concepts of absorbed dose and effective dose, discuss their usefulness in a medical context, and estimate typical dose levels encountered in diagnostic imaging and therapeutic procedures
- Describe the main stochastic effects and tissue reactions associated with ionizing radiation exposure, and calculate an approximate indicator of possible risk based on the effective dose
- Describe the operating principles of an ionization chamber and a semiconductor detector, and cite examples of their applications in medical physics

**Production of x-rays and image quality**

- Describe the image formation chain in X-ray imaging, from X-ray production (tube physics, beam shaping) to detection and digital image display
- Interpret the key image quality parameters (contrast, resolution, noise) and relate them to acquisition parameters.
- Discuss the trade-offs between image quality and patient dose in the task-based approach

**2D projection x-ray imaging**

- Describe the physical principles and technical components of radiographic, mammographic and fluoroscopic systems
- Define and interpret common dose quantities such as dose area product (DAP), entrance surface air kerma (ESAK) and average glandular dose (AGD)
- Identify the basic principles of time, distance and shielding in radiation protection scenarios and explain the connection between radiation protection for patients and for personal.

**3D computed tomographic imaging**

- Describe the physical principles and technical components of computed tomography systems.
- Interpret the influence of the acquisition and reconstruction parameters on the image quality.
- Define dose quantities such as CTDI and DLP and explain their significance and impact on dose management.

**Advanced techniques and research in x-ray imaging**

- Briefly describe the most promising advanced techniques in x-ray imaging
  - Details to be provided during the lecture

**Radioisotopes and biokinetics in nuclear medicine**

- Distinguish between the different types of radioactive decay and their potential use in nuclear medicine
- Illustrate the mechanisms of action of a radiopharmaceutical product and their methods of production
- Explain the concept of biokinetic models and internal dosimetry formalism and use them in applied settings.

**Gamma-camera/SPECT and dosimetric devices**

- Explain the main components of a gamma-camera/SPECT device and its functioning
- Explain the working principle of different dosimetric devices (activimeter, dose rate meter, spectrometer, contamination monitor)
- Identify the different fields of clinical and radiological protection applications

**PET and radionuclide therapy**

- Explain the main components of a PET device and identify the different fields of clinical applications
- Explain the workflow required to perform dosimetry in nuclear medicine
- Apply internal dosimetry concepts to real clinical scenarios

**Advanced techniques and research in nuclear medicine**

- Briefly describe the most promising advanced techniques in nuclear medicine
  - Details to be provided during the lecture

**Treatment machines and patient flux in external radiation therapy**

- Explain the objectives of radiation therapy
- Describe the general workflow of a patient in radiation therapy
- Describe the functioning of a medical linear accelerator

**Treatment planning system and dosimetry**

- Present the process and aims of treatment planning
- List the key components of a treatment planning system
- Cite and describe the main dose calculation algorithms

**Imaging and motion management in external radiation therapy**

- Explain the different uses of imaging in radiation therapy
- Compare different imaging modalities and explain their specific interest for radiation therapy
- Describe the principle of tracking, gating and motion management

**Advanced techniques and research in external radiation therapy**

- Briefly describe the most promising advanced techniques in x-ray imaging
  - Details to be provided during the lecture

**Non-ionizing radiations in medical physics and the job of medical physicist**

- Explain the function of the main components of an MRI system and describe the basic principles involved in acquiring an MRI image
- Describe the path of an ultrasonic wave in a medical imaging system, from the transmitter to the detector, and explain

how this information is used to generate an image

• Identify and describe several medical applications of optical radiation in both diagnostics and therapy

• Explain the role of a medical physicist in a hospital, describe their typical responsibilities, and identify the qualifications required for employment in a clinical setting

## Keywords

medical imaging, radiation therapy, radiation in medicine

## Learning Prerequisites

### Recommended courses

This course has many synergies with the Radiation biology, protection and applications course (PHYS-450) where the basics of radiation physics and some aspects of radiation protection are very useful to follow the present course.

## Learning Outcomes

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

• Describe the main parts of an x-ray device from a physical point of view

• Describe the main differences between the radiography units and the fluoroscopy units

• Explain the principle of CT image acquisition

## Teaching methods

Ex-cathedra with integrated individual exercises
The course includes not only lectures and classroom exercises at EPFL, but also illustrative visits to Lausanne University Hospital (CHUV).

## Assessment methods

Written, Multiple Choice Question exam

## Resources

### Bibliography

• The Essential Physics of Medical Imaging, Third Edition, Jerrold T. Bushberg, J. Anthony Seibert, Edwin M. Leidholdt Jr., John M. Boone, Lippicott 2012

• Physics in nuclear medicine, S.R. Cherry, J.A. Sorenson, M.E. Phelps, Saunders Elsevier 2012 (forth edition)

• Radiation Oncology Physics: a handbook for teachers and students, E. Podgorsak, IAEA, 2005, https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1196_web.pdf

### Ressources en bibliothèque

• Find the references at the Library

### Références suggérées par la bibliothèque

• Radiation Oncology Physics: a handbook for teachers and students / Podgorsak

### Moodle Link

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

PHYS-448

# Introduction to particle accelerators

Pieloni Tatiana

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

| | |
|---|---|
| Language of teaching | English |
| Credits | 4 |
| Session | Winter |
| Semester | Fall |
| Exam | Written |
| Workload | 120h |
| Weeks | 14 |
| **Hours** | **4 weekly** |
| Courses | 2 weekly |
| Exercises | 2 weekly |
| **Number of positions** | |

## 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

## Teaching methods

lecture based teaching using slides and blackboard,
occasionally inquiry based learning,
using Jupiter notebooks to simulate accelerator dynamics,

Application of knowledge through concrete exercises and provision of individual feedback in tutorials

## 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 |
|---|---|---|
| Civil Engineering | MA1, MA3 | Opt. |
| 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 of teaching | English |
| Credits | 4 |
| Session | Winter |
| Semester | Fall |
| Exam | Oral |
| Workload | 120h |
| Weeks | 14 |
| **Hours** | **4 weekly** |
| Courses | 2 weekly |
| Exercises | 2 weekly |
| **Number of positions** | |

## 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 environomic 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 ind ustrial 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

-Quizz during the lecture sessions
- Group project
- An oral exam will concern the theory and its application in the case study.

## Supervision

| | |
|---|---|
| Office hours | Yes |
| Assistants | Yes |
| Forum | Yes |

## 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/

EPFL

PHYS-640

# Neutron and X-ray Scattering of Quantum Materials

Lacmann Tom, Rønnow Henrik M., Schmitt Thorsten

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

| | |
|---|---|
| Language of teaching | English |
| Credits | 4 |
| Session | Winter |
| Semester | Fall |
| Exam | Oral |
| Workload | 120h |
| Weeks | 14 |
| **Hours** | **4 weekly** |
| Courses | 2 weekly |
| Exercises | 2 weekly |
| **Number of positions** | |

## Frequency

Every year

## Remark

Next time: Fall 2026

## 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

### Recommended courses

Magnetism in Materials

## Learning Outcomes

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

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

## Assessment methods

Oral

## 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

### Ressources en bibliothèque

- Find the references at the Library

### Références suggérées par la bibliothèque

- Neutron scattering : Theory, Instrumentation and Simulation / Lefmann

### Websites

- https://lqm.epfl.ch

### Moodle Link

- https://go.epfl.ch/PHYS-640

EPFL

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 of teaching | English |
| Credits | 4 |
| Session | Winter |
| Semester | Fall |
| Exam | Oral |
| Workload | 120h |
| Weeks | 14 |
| **Hours** | **4 weekly** |
| Courses | 2 weekly |
| Exercises | 2 weekly |
| **Number of positions** | |

## 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:

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

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

| | |
|---|---|
| Language of teaching | English |
| Credits | 4 |
| Session | Winter |
| Semester | Fall |
| Exam | Written |
| Workload | 120h |
| Weeks | 14 |
| **Hours** | **4 weekly** |
| Courses | 2 weekly |
| Exercises | 2 weekly |
| **Number of positions** | |

### Remark

Pas donné en 2025-26

### 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.

### Keywords

Nuclear data, interaction, reaction, uncertainty, spent nuclear fuel

### 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. |
| Computational science and engineering minor | H | Opt. |
| Ing.-math | MA1, MA3 | Opt. |
| Mathématicien | MA1, MA3 | Opt. |
| Nuclear engineering | MA1 | Opt. |

| | |
|---|---|
| Language of teaching | English |
| Credits | 5 |
| Session | Winter |
| Semester | Fall |
| Exam | Oral |
| Workload | 150h |
| Weeks | 14 |
| **Hours** | **4 weekly** |
| Courses | 2 weekly |
| Exercises | 2 weekly |
| **Number of positions** | |

## Remark

Pas donné en 2025-26 *** Cours donné en alternance tous les deux ans.

## Summary

Cours donné en alternance tous les deux ans

## Content

## Keywords

Partial differential equations, saddle point problems, finite element method, Galerkin approximation, stability and convergence analysis.

## Learning Prerequisites

### Required courses

Analysis I II III IV, Numerical Analysis, Numerical Approximations of PDEs

### Recommended courses

Sobolev spaces and elliptic equations,

### Important concepts to start the course

- Basic knowledge of functional analysis: Banach and Hilbert spaces, L^p spaces.
- Some knowledge on theory of PDEs: classical and weak solutions, existence and uniqueness.
- Basic concepts in numerical analysis: stability, convergence, condition number, solution of linear systems, quadrature formulae, finite difference formulae, polynomial interpolation.
- Basic information on finite element theory for elliptic problems

## Learning Outcomes

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

- Identify features of a PDE relevant for the selection and performance of a numerical algorithm.
- Assess / Evaluate numerical methods in light of the theoretical results.
- Implement numerical methods for saddle point problems

- Choose an appropriate method to solve a given differential problem
- Prove convergence of a discretisation scheme

## Transversal skills

- Write a scientific or technical report.
- Make an oral presentation.

## Teaching methods

Ex cathedra lectures, exercises in the classroom and computer lab sessions.

## Expected student activities

- Attendance of lectures.
- Completing exercises.
- Solving problems with an academic software as Free FEM ++

## Assessment methods

Oral

## Supervision

| | |
|---|---|
| Office hours | Yes |
| Assistants | Yes |
| Forum | Yes |

## Resources

### Bibliography


- S.C. Brenner, L.R. Scott. *The Mathematical Theory of Finite Element Methods*. Springer 2007.
- A. Ern, J-L. Guermond, *Theory and Practice of Finite Elements.* Springer 2004.
- D. Boffi, F. Brezzi, M. Fortin *Mixed Finite elements and Applications*, Springer Verlag. 2013.


### Ressources en bibliothèque

- The Mathematical Theory of Finite Element Methods / S.C. Brenner & L.R. Scott
- Mixed Finite elements and Applications / D. Boffi, F. Brezzi & M. Fortin
- Theory and Practice of Finite Elements / A. Ern & J-L. Guermond

### Notes/Handbook

Notes for each lectures will be provided every week.

### 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, Manera Annalisa, Pautz Andreas

| Cursus | Sem. | Type |
|---|---|---|
| Nuclear engineering | MA1 | Obl. |

| | |
|---|---|
| Language of teaching | English |
| Credits | 6 |
| Session | Winter |
| Semester | Fall |
| Exam | Oral |
| Workload | 180h |
| Weeks | 14 |
| **Hours** | **6 weekly** |
| Courses | 4 weekly |
| Exercises | 2 weekly |
| **Number of positions** | |

## 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 of teaching | English |
| Credits | 6 |
| Session | Winter |
| Semester | Fall |
| Exam | Oral |
| Workload | 180h |
| Weeks | 14 |
| **Hours** | **5 weekly** |
| Courses | 2 weekly |
| Exercises | 3 weekly |
| **Number of positions** | |

## 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 of teaching | English |
| Credits | 6 |
| Withdrawal | Unauthorized |
| Session | Winter |
| Semester | Fall |
| Exam | During the semester |
| Workload | 180h |
| Weeks | 14 |
| **Hours** | **4 weekly** |
| TP | 4 weekly |
| **Number of positions** | **30** |

**It is not allowed to withdraw from this subject after the registration deadline.**

## 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 with the EPFL reactor CROCUS.

## Content

- Radiation detector systems, alpha and beta particles
- Radiation detector systems, gamma spectroscopy
- Introduction to neutron detectors (He-3, BF3)
- Fast neutron detection via Pulse Shape Discrimination
- Approach-to-critical experiments
- Reactor period measurements
- Reactor power calibration
- Neutron noise experiment

## 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)


### Ressources en bibliothèque

- Find the references at the Library

### 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 of teaching | English |
| Credits | 4 |
| Session | Winter |
| Semester | Fall |
| Exam | Written |
| Workload | 120h |
| Weeks | 14 |
| **Hours** | **3 weekly** |
| Courses | 2 weekly |
| Exercises | 1 weekly |
| **Number of positions** | |

## 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
- Operational radiation protection: Sources, Shielding, Calculations
- Internal and external exposure to radionuclides and radiation
- Emergency dosimetry and extreme radiological events
- International nuclear safeguards
- Industrial applications: food irradiation, radioisotope batteries, radiation imaging, etc.
- Applications in research: dosimetry for radiotherapy, metrology, 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
- Contextualise extreme radiological events

### 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

- Find the references at the Library

#### 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 of teaching | English |
| Credits | 4 |
| Session | Winter |
| Semester | Fall |
| Exam | Oral |
| Workload | 120h |
| Weeks | 14 |
| **Hours** | **3 weekly** |
| Courses | 2 weekly |
| Exercises | 1 weekly |
| **Number of positions** | |

## 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

- Find the references at the Library

### Moodle Link

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

ETH-590

# Semester Project Nuclear Engineering

Profs divers *

| Cursus | Sem. | Type |
|---|---|---|
| Nuclear engineering | MA3 | Obl. |

| | |
|---|---|
| Language of teaching | English |
| Credits | 8 |
| Session | Winter |
| Semester | Fall |
| Exam | During the semester |
| Workload | 240h |
| Weeks | 14 |
| **Hours** | **8 weekly** |
| Project | 8 weekly |
| **Number of positions** | |

## 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 d'enseignement | |
| Crédits | 8 |
| Session | Hiver, Eté |
| Semestre | Printemps |
| Examen | Pendant le semestre |
| Charge | 240h |
| Semaines | 14 |
| Projet | 8 hebdo |
| **Nombre de places** | |

## 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 languages et cultures différentes.

## Méthode d'évaluation

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