EPFL

PHYS-761

Advanced radiation sources

Carbone Fabrizio, Invited professor(s) , Puppin Michele

Cursus	Sem.	Type
Physicien	MA1, MA3	Opt.
Physics		Opt.

Language	English
Credits	4
Session	Winter
Semester	
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Frequency

Every year

Summary

This course introduces the basic principles of lasers to then focus on the latest developments in ultrafast radiation sources, including X-ray and gamma-ray sources, attosecond pulses generation, free electron lasers, ultrashort electron pulses and atomic lasers.

Content

1.Basic principles of lasers L1-L2
Population inversion, light amplification, Cavity and feedback. Some laser types: Solid state laser (YAG), Semiconductor lasers, Gas-lasers, Excimers lasers, Vibronic lasers (Ti:Saph), Glass lasers, Rotonic lasers (CO2), Fiber lasers (principles, the nonlinear Schrodinger equation and the propagation of solitons)
2. Optical properties of coherent light sources L3-L4
Coherence (transverse and longitudinal) (broadely defined for all particles, photons, electrons, neutrons, protons)

Radiation/matter interaction L5
Nonlinear optics (Pockels effect, Second harmonc generation, third harmonic generation, four wave mixing, optical parametric amplification, Raman and Brillouin effect)

Pulsed laser operation L6-L7
Q-switching and mode-Locking, Laser amplification: Regenerative and non regenerative amplification of fs pulses

High-energy laser sources L8-L9
Radiation generation mechanisms, fundamental principles, Compton effect, Smith-Purcell effect, Cerenkov effect, Bremstralung, beam accelerators for radiation generation, ultrashort electron pulses (femtosecond and attosecond), Synchrotron radiation

High-harmonics generation L10-L11
principles and methods of HHG in gases and solids

X-ray lasers (principles) L12-L13
Free electron laser (principles, SASE vs seeded operation)

Exotic lasers L14
Microwave lasers (MASER), Phononic laser, Atomic lasers, Gamma-ray laser (wishes and ideas)

During the excercise sessions a 50-50 distribution of theoretical excercises and laboratory activities will be planned. The goal will be to understand how to model and predict the basic characteristics of a radiation source (theory) and how to operate the most common femtosecond lasers and electron sources (experimental activity at the LACUS facilities).

Note

Invited lecturer: Prof. Steven Johnson, ETHZ johnson@phys.ethz.ch

Keywords

ultrafast, ultrashort, laser, radiation, femtosecond, attosecond, coherence

Learning Prerequisites

Required courses

Basic knowledge of electromagnetism and quantum mechanics are necessary for this course

Learning Outcomes

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

- Operate Simple pulsed laser sources
- Describe the newest radiation sources
- Describe the majority of currently available sources
- Design Simple ultrafast laser sources
- Describe high-energy radiation sources
- Operate Simple pulsed electron sources

Resources

Bibliography

Some of the material can be found on classic books such as "Principles of lasers" by Orazio Svelto. Other material will be distributed in class.

Moodle Link

- https://go.epfl.ch/PHYS-761

PHYS-465 Astrophysics III : galaxy formation and evolution

Hirschmann Michaela

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

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

Summary

Galaxy formation & evolution is about studying how galaxies in our Universe come into existence, how they evolve and what shapes their properties. This course describes the observational facts of galaxies and the various processes of galaxy evolution as seen from theoretical/numerical models.

Content

- *Lecture 1 (Repetition of Astro-I and Astro-II)*:
  - Introduction (galaxy definition, astronomical scales, observable quantities)
  - Brief review on stars

- *Lecture 2*:
  - Radiation processes in galaxies and telescopes;
  - The Milky Way

- *Lecture 3*: The world of galaxies I
- *Lecture 4*:
  - The world of galaxies II;
  - Black holes and active galactic nuclei

- *Lecture 5:*
  - Galaxies and their environment;
  - High-redshift galaxies

- *Lecture 6*:
  - Cosmology in a nutshell
  - Linear structure formation in the early Universe

- *Lecture 7*:
  - Dark matter and the large-scale structure
  - Cosmological N-body simulations of dark matter

- *Lecture 8*: Populating dark matter halos with baryons:

- Semi-empirical models
- Semi-analytical models

- *Lecture 9:* Modelling the evolution of gas in galaxies: Hydrodynamics
- *Lecture 10*:
  - Gas cooling/heating
  - Star formation

- *Lecture 11*: Stellar feedback processes
- *Lecture 12*: Black hole growth and AGN feedback
- *Lecture 13*: Success and challenges of modern simulations
- *Lecture 14*: Future prospects and mock exam

Keywords

Astrophysics, Galaxies formation and evolution, Observations, Theoretical/numerical models of galaxies

Learning Prerequisites

Recommended courses

- Bachelor in physics or mathematics
- Astrophysics I, II (but there will be some revision)
- Basics in Python programming

Learning Outcomes

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

- Theorize fundamental principles of galaxy formation and evolution
- Interpret observational results of galaxies
- Analyze observational data and theoretical/numerical simulations

Transversal skills

- Access and evaluate appropriate sources of information.

Teaching methods

Ex cathedra and exercices supervised in classroom.

Assessment methods

oral exam (100%).

Resources

Bibliography

- Extragalactic Astronomy and Cosmology (P. Schneider)
- Galaxy formation and evolution (Mo, van den Bosch & White)

• Galaxy formation (Longair)

Ressources en bibliothèque

• Extragalactic Astronomy and Cosmology / Schneider
• Galaxy formation and evolution / Mo, van den Bosch & White)
• Galaxy formation /Longair

Moodle Link

• https://go.epfl.ch/PHYS-465

EPFL

PHYS-401 **Astrophysics IV : stellar and galactic dynamics**

Revaz Yves

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.
Space technologies minor	E	Opt.

Language	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

The aim of this course is to acquire the basic knowledge on specific dynamical phenomena related to the origin, equilibrium, and evolution of star clusters, galaxies, and galaxy clusters.

Content

1. Introduction: distances, sizes, masses of stellar dynamics systems such as star and galaxy clusters

2. Potential theory

3. Stellar Orbits

4. Equilibria of collisionless systems

5. Stability of collisionless systems

6. Disk dynamics and the formation of spiral structures

Learning Prerequisites

Recommended courses

Bachelor in physics or mathematics and Astrophysics I and II

Learning Outcomes

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

- Theorize the laws of stellar dynamics

Transversal skills

- Access and evaluate appropriate sources of information.

Teaching methods

Ex cathedra and exercises supervised in classroom

Assessment methods

oral exam (100%)

Resources

Moodle Link

- https://go.epfl.ch/PHYS-401

EPFL

PHYS-402

Astrophysics V : observational cosmology

Kneib Jean-Paul

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.

Language	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

Cosmology is the study of the structure and evolution of the universe as a whole. This course describes the principal themes of cosmology, as seen from the point of view of observations.

Content

1. A brief historical perspective: a few ancient cosmologies. Olbers' paradox.

2. The three observational pillars of Big Bang cosmology dis-covered during the 20th century: (i) The universe expansion; (ii) The cosmic microwave background at 3K; (iii) The abundance of light elements.

3. The metric of the universe. The spectral redshifts.

4. Cosmological models and the evolution of the universe.

5. Observational tests: the age of the universe, mean density and the problem of dark matter, nucleo-cosmo-chronology, the deep galaxy counts.

6. Recent observations of the cosmic microwave background and its power spectrum.

7. Impact of gravitational lenses on cosmology.

8. The initial phases of the evolution of the universe in the Big Bang model and cosmological nucleosynthesis.

Learning Prerequisites

Recommended courses

Bachelor in physics or mathematics and Astrophysics I, II and III

Learning Outcomes

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

- Theorize the fondamental principles of cosmology

Transversal skills

- Access and evaluate appropriate sources of information.

Teaching methods

Ex cathedra and exercices supervised in classroom

Assessment methods

oral exam (100%)

Resources

Ressources en bibliothèque

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Moodle Link

- https://go.epfl.ch/PHYS-402

PHYS-302

Biophysics : physics of biological systems

Rahi Sahand Jamal

Cursus	Sem.	Type
Biomedical technologies minor	H	Opt.
Ing.-phys	MA1, MA3	Opt.
Life Sciences Engineering	MA1, MA3	Opt.
Mechanical engineering	MA1, MA3	Opt.
Physicien	MA1, MA3	Opt.
Physics of living systems minor	H	Opt.
Physics		Opt.

Language	English
Credits	4
Session	Winter
Semester	Fall
Exam	During the semester
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

Understand and use the results and methods of population genetics, population dynamics, network theory, and reaction network dynamics to analyze and predict the behavior of living systems

Content

Master equation, population genetics, finite populations, genetic drift, stochastic modeling, fluctuating environments

Introduction to networks, dynamics on networks

Biochemical reaction networks, Michaelis-Menten kinetics, cooperativity, autoregulation, feedback and bistability, switches, oscillations, feed-forward loop network motif, stochastic gene expression, causes and consequences of stochastic gene expression, robustness

Keywords

physics of living systems, population genetics, population dynamics, genetic networks, systems biology

Learning Prerequisites

Recommended courses

physics, mathematics, and biology at the introductory university level

Teaching methods

Flipped classroom, lectures (online and in person), in-person discussions, discussions of research articles, problem solving

Expected student activities

attend lectures, watch online lectures, complete exercises, read and present recent papers in the field

Assessment methods

40% homework, 60% final project

Supervision

Office hours	Yes
Assistants	Yes

Resources

Moodle Link

- https://go.epfl.ch/PHYS-302

EPFL

PHYS-463 **Computational quantum physics**

Carleo Giuseppe

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Minor in Quantum Science and Engineering	E	Opt.
Physicien	MA2, MA4	Opt.
Quantum Science and Engineering	MA2, MA4	Opt.

Language	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

The numerical simulation of quantum systems plays a central role in modern physics. This course gives an introduction to key simulation approaches, through lectures and practical programming exercises. Simulation methods based both on classical and quantum computers will be presented.

Content

1. **Single-particle Problems:** Numerical solutions of the Schroedinger equation, Numerov's integration, the split operator method

2. **Quantum Spin Models**: Choice and representations of basis sets for the many-body problem, the Trotter decompososition for real and imaginary-time evolution

3. **Electronic Structure**: Second Quantization, Full Configuration Interaction, Hartree-Fock, Density Functional Theory

4. **Variational Methods**: Variational Monte Carlo. Machine Learning Based Techniques, Time-dependent Variational Approaches

5. **Quantum Monte Carlo Methods**: Path Integral Monte Carlo at finite and zero temperature

6. **Quantum Computing**: Quantum simulation on a quantum computer, Adiabatic State preparation, Variational Quantum Eigensolver

Keywords

Quantum simulation, Variational Monte Carlo, Machine Learning in Physics, Density Functional Theory, Lanczos, Path Integral Monte Carlo, Quantum Computing, Second Quantization, Time-Dependent Variational Principle

Learning Prerequisites

Required courses

A solid understanding of quantum mechanics (I and II) is required.
Students should have a good working knowledge of at least one common programming language (Python, C, C++, Fortran, Julia...). Knowledge of Matlab is typically sufficient, but it is strongly advised to be familiar with Python, since the exercises will be typically presented and discussed in Python.

Recommended courses

-

Learning Outcomes

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

- Model a quantum problem through numerical tools
- Identify suitable algorithms to solve or approximately solve a certain quantum problem
- Discuss the limitations of a given algorithm
- Carry out computer simulations

Teaching methods

Ex cathedra with exercises

Expected student activities

Practical assignments will be given every week.
Solutions to the assignements will be handed out and the homework will not be graded.
It is strongly advised however to make the effort to do the homework weekly, since the final exam will also evaluate the understanding of the practical implementation aspects of the computational methods.

Assessment methods

The course is graded through an oral exam.
The oral exam will assess both the general theory as well as the understanding of the practical implementation of the algorithms, as presented during the practical weekly exercises.

Resources

Bibliography

Suggested books to acquire a broader view on the topics discussed in the lecture notes
"Quantum Monte Carlo Approaches for Correlated Systems", F. Becca & S. Sorella, (Cambridge University Press, 2017)
"Computational Physics", J. M. Thijssen, (Cambridge University Press)
"Statistical Mechanics: Algorithms and Computations", W. Krauth, (Oxford Master Series in Physics)

Ressources en bibliothèque

- Computational Physics / Thijssen
- Statistical Mechanics: Algorithms and Computations / Krauth
- Quantum Monte Carlo Approaches for Correlated Systems / Becca

Moodle Link

- https://go.epfl.ch/PHYS-463

PHYS-403

Computer simulation of physical systems I

Pasquarello Alfredo

Cursus	Sem.	Type
Computational science and Engineering	MA1, MA3	Opt.
Ing.-phys	MA1, MA3	Opt.
Mechanical engineering	MA1, MA3	Opt.
Physicien	MA1, MA3	Opt.

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

Summary

The two main topics covered by this course are classical molecular dynamics and the Monte Carlo method.

Content

Ordinary differential equations: methods for numerical integration: multistep algorithms and implicit algorithms.

Classical molecular dynamics: Verlet algorithm, predictor-corrector algorithms, determination of macroscopic parameters, Nosé-Hoover thermostat, constraints, Ewald summations, application to Lennard-Jones liquids.

Random variables: definitions and properties, generators and distribution functions, central-limit theorem.

Random walks: binomial and Gaussian distributions, particle diffusion, Brownian motion.

Monte Carlo integration: direct sampling, importance sampling, Metropolis algorithm, errors in correlated sampling, Monte-Carlo simulations of Lennard-Jones liquids and of two-dimensional spin systems.

Learning Prerequisites

Recommended courses

Statistical physics

Learning Outcomes

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

- Model a physical problem by a computer simulation
- Interpret experimental properties using a computer program
- Carry out computer simulations
- Synthesize results in the form of a scientific report

Assessment methods

Report + oral exam = 1 grade

Resources

Virtual desktop infrastructure (VDI)

Yes

Ressources en bibliothèque

- Computational physics : an introduction / F.J. Vesely
- Computational physics / S. E. Koonin
- Computational physics / J. M. Thijssen

Websites

- http://moodle.epfl.ch/course/view.php?id=3711

Moodle Link

- https://go.epfl.ch/PHYS-403

EPFL

MSE-450 Electron microscopy: advanced methods

Alexander Duncan

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Materials Science and Engineering	MA2, MA4	Opt.
Minor in Imaging	E	Opt.
Physicien	MA2, MA4	Opt.

Language	English
Credits	3
Session	Summer
Semester	Spring
Exam	During the semester
Workload	90h
Weeks	14
Hours	**3 weekly**
Lecture	2 weekly
Exercises	1 weekly
Number of positions	

Summary

With this course, the student will learn advanced methods in transmission electron microscopy, especially what is the electron optical setup involved in the acquisition, and how to interpret the data. After the course, students will be able to understand and assess TEM encountered in papers.

Content

1. Electron imaging and diffraction contrasts
2. Phase contrast
3. Scanning TEM
4. EDS-, EEL-spectroscopy in TEM.

Exercises and demonstrations concerning these themes.

Learning Prerequisites

Required courses

- Electron microscopy : introduction
- Basic knowledge of Solid state physics, Crystallography, Crystal defects

Learning Outcomes

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

- Choose the appropriate TEM technique adapted to their problems
- Recognize The TEM techniques used in a publication
- Interpret TEM images
- Present the TEM results

Teaching methods

Seven weeks of the course will be with MOOCS, 7 weeks with conventional format, alternating over the semestre.
The weeks with MOOCS format, there will be time reserved at the microscope(s) to discuss and practice on the TEM the content of the lecture, as well as to answer student's questions.

Expected student activities

Follow the MOOCS *before* attending the TEM session for the 7 weeks on MOOCS format.

Assessment methods

Project based evaluation with one individual report + oral evaluation during the exam period.
The written report has to be submitted at last, Friday of the second week after the end of the teachings. Each student will be indivudually interviewed based on this report during the exam session.
The grade will be 50% written report 50% oral exam.

Resources

Bibliography

Transmission Electron Microscopy
A Textbook for Materials Science
Williams, David B., **Carter**, C. Barry

Ressources en bibliothèque

- Electron energy loss spectroscopy / Egerton
- Transmission electron microscopy : a textbook for materials science / Carter
- Transmission electron microscopy diffractometry of materials / Fultz

Moodle Link

- https://go.epfl.ch/MSE-450

EPFL

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
Hours	**3 weekly**
Lecture	2 weekly
Exercises	1 weekly
Number of positions	

Summary

The course's objectivs are: Learning several advenced 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 spectroscopys: 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 tecniques, 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

PHYS-407

Frontiers in nanosciences

Kern Klaus, Pivetta Marina, Rusponi Stefano

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

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

Summary

The students understand the relevant experimental and theoretical concepts of the nanoscale science. The course move from basic concepts like quantum size effects to ##hot fields## such as spin transport for data storage applications (spintronics), carbon electronics, or nanocatalysis.

Content

1. Introduction to the concepts of nanoscale science
2. The art of making nanostructures:
a. Bottom-up assembly
b. Top-down fabrication
3. Quantum structures and devices:
a. Current at the nanoscale
b. Quantum technology
4. Carbon nanotechnology:
a. From fullerenes to graphene
b. Molecular electronics and machines
5. Microscopy and manipulation tools:
a. Electron microscopy
b. Scanning probe microscopy: STM, AFM, MFM
6. Spectroscopy tools:
a. Electron and photon spectroscopy: XPS, XAS, Auger
b. Electron and photon diffraction: LEED, TEM, SXRD
c. Synchrotron radiation
7. Magnetism at the nanoscale:
a. Orbital and spin magnetic moment
b. Superparamagnetic limit in magnetic data storage
8. From electronics to spintronics:
a. 2D electron gas at heterogeneous semiconductor interfaces
b. Single electron transistor
c. Spin transport: spin valve, GMR and TMR effects

Learning Prerequisites

Recommended courses

Solid state physics

Learning Outcomes

• Explain the differences between nanoscopic and macroscopic scale

- Analyze the results of a scientific experiment
- Design a scientific experiment

Transversal skills

- Summarize an article or a technical report.
- Access and evaluate appropriate sources of information.
- Use a work methodology appropriate to the task.

Teaching methods

Ex cathedra with visiting of laboratories at EPFL and the Max-Planck-Institute for Solid State Research in Stuttgart, Germany

Assessment methods

oral exam (100%)

Resources

Ressources en bibliothèque

- Quantum Transport, Atom to Transistor / Datta
- Physics of surfaces and interfaces / Ibach
- Surfaces and interfaces of solids / Lüth
- Introduction to Nanoscience / Lindsay
- Physics at surfaces / Zangwill

Websites

- http://moodle.epfl.ch/course/view.php?id=7781

Moodle Link

- https://go.epfl.ch/PHYS-407

PHYS-438

Fundamentals of biomedical imaging

Gruetter Rolf

Cursus	Sem.	Type
Auditeurs en ligne	E	Opt.
Biomedical technologies minor	E	Opt.
Computational Neurosciences minor	E	Opt.
Electrical Engineering		Opt.
Electrical and Electronical Engineering	MA2, MA4	Opt.
Ing.-phys	MA2, MA4	Opt.
Life Sciences Engineering	MA2, MA4	Opt.
Minor in Imaging	E	Opt.
Neuro-X minor	E	Opt.
Neuro-X	MA2, MA4	Opt.
Neuroprosthetics minor	E	Opt.
Photonics		Opt.
Physicien	MA2, MA4	Opt.
Physics of living systems minor	E	Opt.

Language	English
Credits	4
Session	Summer
Semester	Spring
Exam	Written
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

The goal of this course is to illustrate how modern principles of basic science approaches are integrated into the major biomedical imaging modalities of importance to biology and medicine, with an emphasis on those of interest to in vivo.

Content

1. Introduction to the course, importance and essential elements of bioimaging - lab visit of CIBM
2. Ultrasound imaging; ionizing radiation and its generation
3. X-ray imaging - when the photon bumps into living tissue, radioprotection primer
4. Computed tomography - From projection to image
5. Emission tomography - what are tracers and how to "trace" them in your body, x-ray detection, scintillation principle
6. Positron emission tomography (PET) - imaging anti-matter annihilation
7. Tracer kinetics - modeling of imaging data
8. Introduction to biological magnetic resonance (MR) - Boltzmann distribution, from spins to magnetization
9. Excitation of spins, Relaxation, the Basis of MR contrast (The Bloch Equations)
10. MR spectroscopy: In vivo Biochemistry, without chemistry ...
11. From Fourier to image: Principles of MR image formation, k-space - echo formation
12. Basic MRI contrast mechanisms, BOLD fMRI, contrast agents
13. Spin gymnastics: Imaging Einstein's random walk - fiber tracking. Overview of imaging modalities treated in this course

Keywords

Ultrasound
MRI
PET
SPECT
CT
Radioprotection

Learning Prerequisites

Recommended courses

General Physics I-III

Important concepts to start the course
Fourier transformation

Learning Outcomes
By the end of the course, the student must be able to:
- Deduce which imaging technique is appropriate for a given situation
- Describe their fundamental promises and limitations
- Differentiate the imaging modalities covered in the course

Transversal skills
- Assess one's own level of skill acquisition, and plan their on-going learning goals.
- Manage priorities.

Teaching methods
Ex cathedra with experimental demos

Expected student activities
strong participation in course and exercices

Assessment methods
a written exam

Supervision
Office hours	Yes
Assistants	Yes

Resources
Bibliography
"Introduction to biomedical imaging / Andrew Webb". Année:2003. ISBN:0-471-23766-3
Also available as e-book at EPFL library

Ressources en bibliothèque
- Introduction to biomedical imaging / Webb

Websites
- http://lifmet.epfl.ch/

Moodle Link
- https://go.epfl.ch/PHYS-438

Videos
- http://provided on moodle

PHYS-502 **Interacting quantum matter**

Cursus	Sem.	Type
Ing.-phys	MA1, MA3	Opt.
Minor in Quantum Science and Engineering	H	Opt.
Physicien	MA1, MA3	Opt.
Quantum Science and Engineering	MA1, MA3	Opt.

Language	English
Credits	4
Session	Winter
Semester	Fall
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	3 weekly
Exercises	1 weekly
Number of positions	

Remark

pas donné en 2023-24

Summary

This course presents modern aspects of theoretical condensed matter physics with interfaces to statistical physics, quantum information theory, quantum field theory and quantum simulation.

Content

- Quantum Phase Transitions
- Topological Order
- Entanglement in Quantum Many Body Systems
- Non-Equilibrium Dynamics
- Lattice gauge theories in Condensed Matter and Synthetic Quantum Many Body Systems

Learning Prerequisites

Recommended courses

Solid State Physics III
Statistical physics III

Learning Outcomes

- Theorize modern approaches to interacting quantum matter

Transversal skills

- Continue to work through difficulties or initial failure to find optimal solutions.
- Demonstrate a capacity for creativity.
- Access and evaluate appropriate sources of information.
- Summarize an article or a technical report.

Teaching methods

Ex cathedra and exercises supervised in classroom

Assessment methods

Oral Exam (100%)

Supervision

Office hours	No
Assistants	Yes
Forum	No

Resources

Moodle Link

- https://go.epfl.ch/PHYS-502

EPFL

PHYS-439

Introduction to astroparticle physics

Neronov Andrii, Perrina Chiara, Savchenko Volodymyr

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.

Language	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

We present the role of particle physics in cosmology and in the description of astrophysical phenomena. We also present the methods and technologies for the observation of cosmic particles.

Content

1. The observed universe: cosmological expansion, age of the universe, cosmic microwave background radiation.

2. Dark matter in the Universe. Rotation curves of the galaxies, experiments on detection of dark matter.

3. Astrophysical sources of high-energy gamma quanta and cosmic rays.

4. Pulsars and supernovae. Neutrinos from the supernova SN1987A.

5. High-energy particle acceleration near magnetized neutron stars.

6. Astrophysical black holes: stellar mass black holes and supermassive black holes in the nuclei of active galaxies.

7. High-energy particle acceleration and production of cosmic rays by the black holes.

8. Charged cosmic rays: energy flux and composition; origin and acceleration. Direct detection of cosmic rays: the AMS and DAMPE experiments. Extensive air showers: composition, longitudinal and lateral profiles. The indirect detection of cosmic rays: the Pierre Auger Observatory.

9. Cosmic photons: production mechanisms and sources; the multiwavelength astronomy. Direct detection of cosmic gamma rays: the Fermi experiment. Indirect detection of cosmic gamma rays: imaging atmospheric Cherenkov telescopes and extensive air shower detectors.

10. Solar neutrinos: production, spectra and detection; the solar neutrino problem. Astrophysical neutrinos: production mechanisms and candidate sources. The neutrino astronomy and the neutrino telescopes: IceCube and KM3NeT.

Learning Prerequisites

Recommended courses

Nuclear and particle physics I and II (PHYS-311, PHYS-312)

Learning Outcomes

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

- Analyze the physical phenomena associated with cosmic rays

- Discuss the detection principles of astroparticle physics experiments
- Interpret the main results of selected experiments
- Assess / Evaluate the state of the art of astroparticle physics

Teaching methods

Ex cathedra and classroom exercises

Assessment methods

oral exam (100%)

Resources

Moodle Link

- https://go.epfl.ch/PHYS-439

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
Hours	**4 weekly**
Lecture	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

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

EPFL

MICRO-422

Lasers: theory and modern applications

Kippenberg Tobias, Moser Christophe

Cursus	Sem.	Type
Electrical and Electronical Engineering	MA1, MA3	Opt.
Ing.-phys	MA1, MA3	Opt.
Microtechnics	MA1, MA3	Opt.
Photonics minor	H	Opt.
Photonics		Opt.
Physicien	MA1, MA3	Opt.

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

Summary

This course gives an introduction to Lasers by both considering fundamental principles and applications. Topics that are covered include the theory of lasers, laser resonators and laser dynamics. In addition to the basic concepts, a variety of interesting laser systems and applications are covered

Content

1. Introduction (Overview: History of the laser, Market application, Nobel Prizes,)- demo laser printer.
2. Basics of resonators and Gaussian beam optics.
3. Principle of laser operation: Lorentz model, dispersion theory.
4. Principle of laser operation: Laser oscillation, threshold, coherence.
5. Semiconductor and photonic nanostructured lasers
6. Laser dynamics : Laser oscillation, laser line-width, coherent population oscillations - AM, PM Noise.
7. (Gas and) Solid state lasers Optical fibers
8. Fiber laser and amplifiers Optical fibers
9. Ultrafast lasers, Femtosecond laser Frequency Metrology, Mode locked lasers, autocorrelation, FTIR
10. Ultrafast lasers, Femtosecond laser Frequency Metrology, Mode locked lasers
11. Detection of laser light (detector basics)
12. Optical parametric oscillators (OPO), Raman Lasers
13. Tools of laser light manipulation

Learning Prerequisites

Important concepts to start the course

This course requires an understanding of introductory physics in wave theory (incl. complex numbers) and familiarity with Maxwell equations and electromagnetism.

Learning Outcomes

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

- Able to compute absorption cross-section
- explain in details YAG, He-Ne, Ti-saphirre, external cavity lasers, fiber lasers
- Know shot and thermal noise, laser linewidth, relaxation oscillation
- know passive and active modelocking, methods to caracterize pulse duration
- Know phase matching, method to obtain phase matching
- know parametric gain, singly and doubly resonant lasers

Teaching methods

2 hours of class + 1 hour of exercises
Part of the class will be given via MOOC videos.

Assessment methods

The course grading is based on a final written exam which counts for 80% of the grade and two quizzes during the semester which count for 20% of the grade.

Homework will be given every week. Solutions will be handed out. The quizzes questions are drawn from the class and from the exercises.

Resources

Bibliography

Main text book:
Milonni, Eberly "Laser Physics" (Wiley Interscience)
Additional chapters will be selected from:
Saleh, B. E. A., and M. C. Teich. Fundamentals of Photonics. New York, NY: John Wiley and Sons, 1991. ISBN: 0471839655.
Yariv, A. Optical Electronics in Modern Communications. 5th ed. New York, NY: Oxford University Press, 1997. ISBN: 0195106261.Amnon Yariv "Quantum Electronics" (Wiley)

Ressources en bibliothèque

- Quantum Electronics / Yariv
- Fundamentals of Photonics / Saleh
- Optical Electronics in Modern Communications / Yariv
- Laser Physics / Milonni

Notes/Handbook

Polycopié:
"Theory and applications of lasers" by Tobias J. Kippenberg and Christophe Moser (available as pdf on Moodle)

Moodle Link

- https://go.epfl.ch/MICRO-422

EPFL

PHYS-467

Machine learning for physicists

Zdeborová Lenka

Cursus	Sem.	Type
Chimiste	MA1, MA3	Opt.
Ing.-phys	MA1, MA3	Opt.
Physicien	MA1, MA3	Opt.
Quantum Science and Engineering	MA1, MA3	Opt.

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

Summary

Machine learning and data analysis are becoming increasingly central in sciences including physics. In this course, fundamental principles and methods of machine learning will be introduced and practised.

Content

* Examples and types of problems that machine learning can solve.
* Linear regression in matrix notation. The concept of prediction, estimation. Least squares method. High-dimensional underdetermined problems and the concept of regularization aka ridge regression. Polynomial regression. The concept of bias and variance trade-off and overfitting. Usage of train, validation and test sets.
* Reminder of key concept from probability theory. Bayesian inference, maximum likelihood and maximum a posteriori estimation.
* Least-squares as maximum likelihood of probabilistic model with additive Gaussian noise. Regularization as a prior. Relation with inverse problems in signal processing. Generalized linear model.
* Robust regression, sparse regression, LASSO. Role of sparsity for variable selection. Compressed sensing.
* Gradient descent and stochastic gradient descent.
* Linear classification. Examples of classification losses. Logistic regression and its probabilistic interpretation.
Multi-class classification, one-hot-encoding of classes, cross-entropy loss.Data that are not linearly separable. K-nearest neighbours. Curse of dimensionality.
* Unsupervised learning, dimensionality reduction, low-rank approximation. Singular values decomposition (SVD) and principal component analysis (PCA).
Examples: Recommender systems, reconstruction of Europe geography from human genome, spin-glass card game aka planted spin glass model.
* Analogy between learning/inference in high dimension and statistical mechanics. Maximum a posteriori estimation as search for the ground state.
Minimum mean squared error estimator. Bayesian inference as sampling from the Boltzmann measure.
* Monte Carlo Markov Chains and their basic principles. Metropolis-Hastings update rule.
Gibbs sampling aka heat bath. Simulated annealing.
Bayesian learning of hyper-parameters, expectation maximization algorithm.
* Clustering. The k-means algorithm. Gaussian mixture model.
* Data generative models. Boltzmann machine. Maximum entropy principle. Training algorithm for the Boltzmann machine.
* Non-linear regression as linear regression in feature space. Representor theorem. Kernel methods as infinite-dimensional feature spaces. Kernel ridge regression. Examples of kernels and their feature spaces. Kernels as universal approximations. Classification with kernels, support vector machines.
* Random feature regression as approximation of kernels. One hidden-layer neural networks as features learning machines. Neural networks as universal approximators. Worst case computational hardness of training. Multi-layer neural networks as learning features of features.
* Deep learning for regression and classifications. Terminology of multi-layer feed-forward neural networks. Training with stochastic gradients descent aka the back-propagation algorithm. Discussion of hyper-parameters to be set when using neural networks. Historical notes and comments on performance of deep learning.
Importance of locality and translational symmetry. Convolutional neural networks for image classification. Design and

terminology of convolutional and pooling layers.
Modus operandi of deep neural networks. Over-parametrization and lack of overfitting. Double descent behaviour replaced the bias-variance trade-off. Interpolation of the training set and its consequences for training, implicit regularization.
Concept of transfer learning, adversarial examples, data augmentation.
* Unsupervised learning using tricks from deep learning. Boltzmann machine with hidden variables, restricted Boltzmann machines, contrastive divergence algorithm.
The principle of auto-encoder, its training and usage. Principles of generative adversarial networks (GANs), their usage and training.

Learning Prerequisites

Important concepts to start the course

Basic notions in probability, analysis and basic familiarity with programming. Some notions of statistical physics will be used to support this lecture.

Learning Outcomes

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

- Use basic tools for data analysis and for learning from data
- Explain basic principles of data analysis and learning from data
- List and explain machine learning tools suited for a given problem.

Teaching methods

2h of lecture + 2h of excercise (exercise mostly with a computer)

Assessment methods

Final written exam counting for 50% and several graded homeworks during the semester counting for the other 50%.

Resources

Bibliography

A high-bias, low-variance introduction to Machine Learning for physicists. Pankaj Mehta, Marin Bukov, Ching-Hao Wang, Alexandre G.R. Day, Clint Richardson, Charles K. Fisher, David J. Schwab, https://arxiv.org/abs/1803.08823.

Text book "Information Theory, Inference, and Learning Algorithms" by David MacKay.
Polycopie of the lecture available in Moodle.

Ressources en bibliothèque

- A high-bias, low-variance introduction to Machine Learning for physicists. Pankaj Mehta, Marin Bukov, Ching-Hao Wang, Alexandre G.R. Day, Clint Richardson, Charles K. Fisher, David J. Schwab
- Information Theory, Inference, and Learning Algorithms /David MacKay

Moodle Link

- https://go.epfl.ch/PHYS-467

EPFL

PHYS-491 **Magnetism in materials**

Zivkovic Ivica

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.

Language	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

The lectures will provide an introduction to magnetism in materials, covering fundamentals of spin and orbital degrees of freedom, interactions between moments and some typical ordering patterns. Selected experimental techniques and their application in current research will be presented.

Content

1. Introduction (spin and orbital moments, Pauli matrices)
2. Isolated magnetic moments (diamagnetism, paramagnetism, Hund rules)
3. Crystal fields (ligand environment of magnetic ions, Jahn-Teller effect)
4. Interactions (dipole, direct exchange, super-exchange, anisotropic and asymmetric exchange)
5. Long-range magnetic order (ferromagnetism, Weiss model, critical behavior, excitations)
6. Long-range magnetic order (antiferromagnetism, incommensurate order, spin-glass)
7. Magnetism in metals (Pauli paramagnetism, Stoner mechanism, Landau levels)
8. Magnetism in metals (spin-density wave, RKKY, Kondo effect)
9. Measurement techniques 1 (magnetization, susceptibility)
10. Measurement techniques 2 (specific heat, ESR)
11. Measurement techniques 3 (NMR, muSR)
12. Measurement techniques 4 (neutron scattering)
13. Multiferroics (ferroelectrics, magneto-elastic effect, magneto-caloric effect)

Learning Prerequisites

Required courses

Classical electrodynamics
Quantum Physics 1

Recommended courses

Quantum Physics 2
Solid State Physics 1
Solid State Physics 2

Learning Outcomes

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

- Define fundamental sources of magnetism
- Explain the behavior of magnetic moments in magnetic fields
- Work out / Determine spin states from ligand environment

- Elaborate common magnetic interactions and their properties
- Contrast typical long-range ordered states in magnetism
- Discuss how magnetism arises in metals
- Demonstrate similarities and differences in low-dimensional magnetic systems
- Specify the role of a given experimental technique in investigation of magnetic materials

Transversal skills

- Demonstrate the capacity for critical thinking
- Summarize an article or a technical report.
- Make an oral presentation.

Teaching methods

Lectures with exercises.

Assessment methods

Oral exam.

Supervision

Office hours	Yes
Assistants	Yes
Others	Office hours: appointments can be arranged by email.

Resources

Bibliography

"Magnetism in Condensed Matter Physics", Stephen Blundell (Oxford University Press, 2001)

Ressources en bibliothèque

- Magnetism in Condensed Matter / Blundell

Moodle Link

- https://go.epfl.ch/PHYS-491

PHYS-442

Modeling and design of experiments

Fuerbringer Jean-Marie

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.

Language	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Practical work	2 weekly
Number of positions	

Summary

In the academic or industrial world, to optimize a system, it is necessary to establish strategies for the experimental approach. The DOE allows you to choose the best set of measurement points to minimize the variance of the results. The concepts learned are applicable in all areas.

Content

- Fundamentals of DOE theory and data analysis
- Multilineal regression
- Greaco-Latin squares
- Placket-Burman designs
- Factorial and fractional factorial designs
- Surface response designs
- Mixture designs

Keywords

Design of experiments, ANOVA, Least square fit, Statistics, Multilineal regression, variance minimization

Learning Prerequisites

Recommended courses

Statistics, metrology

Important concepts to start the course

Basic statistical conceps such as average, variance, statistical distributions, Calculus, linear algebra matriciel, Matlab or Python fundamentals, coding fundamentals

Learning Outcomes

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

- Propose an empirical model in function of the experimental objectives
- Analyze an experimental situation and identify the critical elements from a statistical point of view
- Establish a design of experiments in relation with the candidate models and the experimental constraints

Transversal skills

- Plan and carry out activities in a way which makes optimal use of available time and other resources.
- Use a work methodology appropriate to the task.
- Demonstrate the capacity for critical thinking
- Use both general and domain specific IT resources and tools

Teaching methods

Theoretical presentation, cases calculation and analysis

Expected student activities

- Synthesized the theoretical presentation in personal summary with concept maps
- Solve exercise problems

Assessment methods

1/3 Imposed project prepared and reported in group of 3 students
2/3 Oral exam concisting in presenting individually the project (1/3) and answering theoretical question (1/3)

Resources

Bibliography

- Box, G.E.P.; Hunter, J.S.; Hunter, W.G. Statistics for Experimenters; Wiley Series in Probability and Mathematical Statistics, John Wyleyand Son, 1978.
- Montgomery, D.C. Design and analysis of experiments, 7th edition ed.; John Wyley and Son, 2009.
- Davison A.C.; Statistical model, Cambridge University Press in June 2003.
- Ryan Th.; Modern Experimental Design, John Wyley and Son, 2007.

Ressources en bibliothèque

- Modern Experimental Design
- Statistics for Experimenters, An introduction to design, data analysis and model building
- Design and analysis of experiments
- Statistical model

Moodle Link

- https://go.epfl.ch/PHYS-442

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
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

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 spectrosocpy

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 â## Theory, Instrumentation and Simulation"##, lecture notes by Kim Lefmann
Relevant scientific articles

Websites

- http://Lab web page: lqm.epfl.ch

PHYS-460

Nonlinear dynamics, chaos and complex systems

Février Olivier

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.

Language	English
Credits	6
Session	Summer
Semester	Spring
Exam	Oral
Workload	180h
Weeks	14
Hours	**5 weekly**
Lecture	3 weekly
Exercises	2 weekly
Number of positions	

Summary

The course provides students with the tools to approach the study of nonlinear systems and chaotic dynamics. Emphasis is given to concrete examples and numerical applications are carried out during the exercise sessions.

Content

The course consists of three parts.
Part 1: Nonlinear dynamics
- One-dimensional systems and elementary bifurcations
- Two-dimensional systems, phase-plane analysis, limit cycles, and Hopf bifurcations
Part 2: Chaos
- Lorenz system and chaotic dynamics
- Iterated maps, period-doubling, chaos, universality, and renormalization
- Fractals
- Strange attractors
Part 3: Introduction to complex systems
- The science of complexity
- Examples of complex systems, networks, turbulence, etc.

Keywords

Chaos, Nonlinear systems, Complex system, Fractals, Differential equations, Bifurcations.

Learning Prerequisites

Required courses

Introductory Physics and Math courses.

Learning Outcomes

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

- Manipulate the fundamental elements of nonlinear systems and chaotic dynamics

Teaching methods

Ex cathedra and exercises in class.

Assessment methods

Oral Exam

Resources

Bibliography

- S.H. Strogatz, Nonlinear dynamics and chaos, with application to Physics, Biology, Chmistry, and Engineering, Second Edition, Westwiew Press.
- P.G. Drazin, Nonlinear systems, Cambridge University Press.
- M.W. Hirsch, S. Smale, and R.L. Devaney, Differential equations, dynamical systems, and an introduction to chaos, Elsevier.
- M. Dichter, Student solutions manual for Nonlinear dynamics and chaos, Westview Press.

Ressources en bibliothèque

- M.W. Hirsch, S. Smale, and R.L. Devaney, Differential equations, dynamical systems, and an introduction to chaos, Elsevier.
- Dichter / Nonlinear dynamics and chaos - Student solution
- Drazin / Nonlinear systems
- Strogatz / Nonlinear dynamics and chaos

Moodle Link

- https://go.epfl.ch/PHYS-460

PHYS-470

Nonlinear optics for quantum technologies

Cursus	Sem.	Type
Ing.-phys	MA1, MA3	Opt.
Microtechnics	MA1, MA3	Opt.
Minor in Quantum Science and Engineering	H	Opt.
Photonics minor	H	Opt.
Photonics		Opt.
Physicien	MA1, MA3	Opt.
Quantum Science and Engineering	MA1, MA3	Opt.

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

Remark

pas donné en 2023-24

Summary

This course provides the fundamental knowledge and theoretical tools needed to treat nonlinear optical interactions, covering both classical and quantum theory of nonlinear optics. It presents applications such as nonclassical state generation and coherent frequency conversion.

Content

Nonlinear optics is continuously gaining in impact and relevance for the generation and conversion of quantum states of light, with numerous applications to quantum technologies. In parallel, the development of photonic integrated circuits and plasmonic nanocavities offers new opportunities to boost and tailor nonlinear effects. Finally, nonlinear optics offers unlimited possibilities to perform spectroscopy on molecules and nanomaterials and study their electronic and vibrational properties. This course gives an introduction to these contemporary developments.

Block 1. Fundamentals of nonlinear optics

- Introduction: corpuscular view on nonlinear optical phenomena
- Reminders: wave propagation in linear medium with dispersion; paraxial optics
- Nonlinear susceptibility and wave propagation in a nonlinear medium
- The nonlinear susceptibility tensor. Crystal symmetries, phase matching conditions
- Generation of coherent states at new frequencies (OPO, Raman laser, etc.)

Block 2. Quantum theory of nonlinear optics and its applications

- Quantum theory of nonlinear susceptibility (quantisation of matter). Particular case of the two-level approximation.
- Quantum nonlinear optics: quantisation of light in a nonlinear medium
- Effective Hamiltonian of nonlinear interactions
- Generation of nonclassical states of light and their applications in quantum technologies
- Quantum coherent frequency conversion for quantum networks
- Nonlinear optics in low-dimensional structures (waveguids, micro/nano-cavities)

Invited seminars and tutorials from researchers active in some of these fields (quantum frequency conversion, integrated quantum optics, etc.) will complement the lectures and exercises to enrich the course with practical example of ongoing scientific developments.

Keywords

Nonlinear optics, quantum optics, electromagnetism, electrodynamics, spectroscopy, quantum technology, lasers, oscillators, crystals, molecules, nanostructures, quantum correlations, entanglement, photonic integrated circuits, waveguides, optical cavities, plasmonics, photonics

Learning Prerequisites

Recommended courses

A solid background in the following areas is highly recommended: Classical Electromagnetism and Electrodynamics (Maxwell equations, light-matter interaction), Wave mechanics, Fundamentals of Optics.

Important concepts to start the course

Classical Electromagnetism and Electrodynamics (Maxwell equations, light-matter interaction), Wave mechanics, Fundamentals of Optics.

Learning Outcomes

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

- Define the different types of nonlinear interactions of light with a medium
- Describe the macroscopic manifestation and microscopic origin of nonlinear susceptibility
- Model wave propagation in linear and nonlinear media, in waveguides and low-dimensional geometries
- Predict the efficiency of different nonlinear effects in different geometries
- Explain how to derive a quantum theory of nonlinear optics
- Develop models of nonclassical state generation based on nonlinear optics

Transversal skills

- Use a work methodology appropriate to the task.
- Demonstrate a capacity for creativity.
- Take feedback (critique) and respond in an appropriate manner.
- Use both general and domain specific IT resources and tools
- Continue to work through difficulties or initial failure to find optimal solutions.
- Make an oral presentation.
- Summarize an article or a technical report.

Teaching methods

The course will be interactive, with an alternance of blackboard and slide lecturing, hands-on student exercises, questions and discussions. Active participation is expected.
Research seminars by external experts will establish a closer connection to contemporary research and illustrate the concepts seen in the course.

Expected student activities

Self-study before/after the lecture, active participation, asking questions, solving exercises, studying and presenting research papers

Assessment methods

Active participation during the semester including an oral presentation on a research topic (30%); final oral exam (70%)

Supervision

Office hours	Yes
Assistants	Yes
Forum	Yes

Resources

Virtual desktop infrastructure (VDI)

No

Bibliography

- P. N. Butcher and D. Cotter, *The elements of nonlinear optics*
- Robert Boyd: *Nonlinear Optics*
- François Hache: *Optique Non Linéaire*
- G Grynberg, A Aspect and C Fabre, *Introduction to Quantum Optics*
- J. D. Jackson, *Classical electrodynamics*
- J. Vanderlinde, *Classical Electromagnetic Theory*
- B. E. A. Saleh and M. C. Teich, *Fundamentals of Photonics*

Ressources en bibliothèque

- G Grynberg, A Aspect and C Fabre, Introduction to Quantum Optics
- Introduction to nanophotonics / Henri Benisty, Jean-Jacques Greffet, Philippe Lalanne. - 2022
- B. E. A. Saleh and M. C. Teich, Fundamentals of Photonics
- J. D. Jackson, Classical electrodynamics
- P. N. Butcher and D. Cotter, The elements of nonlinear optics
- François Hache: Optique Non Linéaire
- Robert Boyd: Nonlinear Optics
- J. Vanderlinde, Classical Electromagnetic Theory

Notes/Handbook

Hand-written lecture notes will be provided

Moodle Link

- https://go.epfl.ch/PHYS-470

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
Hours	**4 weekly**
Lecture	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:

- 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

EPFL

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
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

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

PHYS-440

Particle detection

Haefeli Guido

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

Language	English
Credits	4
Session	Winter
Semester	Fall
Exam	During the semester
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

The course will cover the physics of particle detectors. It will introduce the experimental techniques used in nuclear and particle physics. The lecture includes the interaction of particles with matter, scintillators, gas detectors, silicon detectors, detectors for particle ID and photo-detectors.

Content

Interaction of particles in matter: ionization (Bethe-Bloch formula), interaction of electrons and photons (electromagnetic showers, radiation length and critical energy).
General characteristics of detectors: linearity, efficiency, resolution and Fano factor.
Gas detectors: ionization, proportional and Geiger-Muller counters, multiwire proportional, drift and time-projection chambers, micro-pattern gas detectors.
Semiconductor detectors: pn junction, silicon and germanium diode detectors, silicon microstrip and pixel detectors.
Scintillators: organic and inorganic scintillators, wavelength shifters and light guides.
Photodetectors: photomultipliers, photodiodes and other alternatives.
Applications: momentum measurement in magnetic fields, calorimetry, particle identification.

Learning Prerequisites

Recommended courses

Elementary particle I, knowledge in nuclear and particle physics

Learning Outcomes

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

- Categorize processes
- Describe energy deposite processes
- Quantify availabe signal

Transversal skills

- Communicate effectively with professionals from other disciplines.

Teaching methods

Slides, blackboard and exercises in class

Assessment methods

Semester work report evaluation 2/3 and presentation 1/3

Supervision

Office hours	No
Assistants	No
Forum	No
Others	During exercises and at office if requried

Resources

Bibliography

K.Kleinknecht: Detectors for Particle Radiation, Cambridge
W.R.Leo: Techniques for Nuclear and Particle Physics Experiments, Springer

Moodle Link

- https://go.epfl.ch/PHYS-440

EPFL

PHYS-415

Particle physics I

Marchevski Radoslav

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

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

Summary

Presentation of particle properties, their symmetries and interactions. Introduction to quantum electrodynamics and to the Feynman rules.

Content

Introduction:
The Standard Model, a step toward Grand Unification.
Particle detection, accelerators.
Relativity, Klein-Gordon and Dirac equations.

Properties of particles:
Mass, charge, lifetime, spin, magnetic moment,...

Symmetries, conservation laws, and the quark model:
Invariance under space translation and rotation, parity, time reversal and charge conjugation. Violation of parity and CP, CPT theorem. Isospin.

QED:
Introduction to QED. Feynman rules. The form factors.
Tests of QED:
Electron-positron annihilation. Electron-proton scattering. Deep inelastic scattering and proton substructure. Electron and muon magnetic moments.

Learning Prerequisites

Recommended courses

Nuclear and Particle Physics I and II, Quantum mechanics I and II

Learning Outcomes

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

- Analyze sub-microscopical phenomena

Teaching methods

Ex cathedra and exercises in class

Assessment methods

oral exam (100%)

Supervision

Assistants Yes

Resources

Bibliography

Mark Thomson, "Modern Particle Physics" (2013)

Ressources en bibliothèque

- Mark Thomson, "Modern Particle Physics" (2013)

Websites

- http://pdg.lbl.gov/

Moodle Link

- https://go.epfl.ch/PHYS-415

EPFL

PHYS-416

Particle physics II

Shchutska Lesya

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.

Language	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

Presentation of the electroweak and strong interaction theories that constitute the Standard Model of particle physics. The course also discusses the new theories proposed to solve the problems of the Standard Model.

Content

Partons and quarks:
Deep inelastic scattering. Annihilation e+e- at LEP, jets and strings.
Weak Interaction:
Fermi's V-A theory. Pion and muon decays. Cabibbo's theory. The W and Z bosons and their observation at the CERN collider.
Model of quarks and QCD:
SU(3) flavour, mesonic and baryonic structure. SU(N). Quarkonium. The Colour.
Gauge Theories and the Standard Model:
Global and local gauge invariance. Yang and Mills theories. Spontaneous symmetry breaking. Electroweak theory SU(2)xU(1), the Higgs mechanism. GUTs, the Grand Unification.

Learning Prerequisites

Recommended courses

Nuclear and Particle Physics I and II, Quantum mechanics I and II

Learning Outcomes

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

- Analyze the sub-microscopical physical phenomena

Teaching methods

Ex cathedra and exercises in class

Assessment methods

oral exam (100%)

Supervision

Assistants	Yes

Resources

Bibliography

Mark Thomson, "Modern Particle Physics" (2013)

Ressources en bibliothèque

- Mark Thomson, "Modern Particle Physics" (2013)

Websites

- http://pdg.lbl.gov/

Moodle Link

- https://go.epfl.ch/PHYS-416

PHYS-471

Particle physics: the flavour frontiers

Marchevski Radoslav

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.

Language	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

This course will present experimental aspects of flavour physics primarily in the quark sector but also in the lepton sector and their role in the development of the Standard Model of particle physics.

Content

Important historical developments will be discussed, including key flavour physics observables and past experiment built to measure them. The course will delve into present state-of-the-art research and its unresolved problems and will discuss possible ways to address them at present and future flavour physics experiments.

Introduction
key theoretical concepts: the Standard Model, weak interactions, the Yukawa sector, quark-mixing matrix, Unitarity triangles, CP violation
Experimental aspects of flavour physics
past and present flavour-physics facilities and experiments, particle production at accelerators, main experimental principles
Flavour physics in the quark sector
meson decays, neutral meson oscillations, measurements of the angles of the Unitarity triangle, CP violation in meson decays, rare decays of K, B, and D mesons,
Test of the standard model and beyond
CKM fits, New physics flavour puzzle, Lepton Flavour Universality tests, charged lepton flavour violation

Keywords

flavour physics, particle physics, quark mixing, CP violation, meson decays

Learning Prerequisites

Recommended courses

Nuclear and Particle Physics I and II, Quantum mechanics I and II, Particle Physics I.

Learning Outcomes

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

- Analyze the sub-atomic physical phenomena
- Elaborate on modern experimental methods in flavour physics

Teaching methods

Ex cathedra and exercises in class

Assessment methods

oral exam (100%)

Supervision

Assistants	Yes

Resources

Bibliography

Sozzi: Discrete symmetries and CP violation (oriented towards experiment)
Sanda and Bigi: CP violation (oriented towards theory and phenomenology)
Yuval Grossman, Philip Tanedo:Lectures on flavour physics (oriented towards theory)

Ressources en bibliothèque

- Lectures on flavour physics / Grossman Tanedo [arXiv]
- Discrete symmetries and CP violation / Sozzi
- CP violation / Sanda & Bigi

Websites

- https://pdg.lbl.gov/

EPFL

PHYS-468 **Physics of life**

Stahlberg Henning

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Life Sciences Engineering	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.
Physics of living systems minor	E	Opt.

Language	English
Credits	4
Session	Summer
Semester	Spring
Exam	Written
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

Life has emerged on our planet from physical principles such as molecular self-organization, thermodynamics, stochastics and iterative refinement. This course will introduce the physical methods to study life and will discuss the quantitative and physical concepts that make life possible.

Content

- The structural organization of life
- Digitalization, Fourier transforms, error propagation, measurement methods
- Energy forms in life: Membrane potential, ATP, concentration gradients, protein folding
- Protein purification: Chromatography, Electrophoresis, Lab Overview
- Hydrodynamic methods, viscosity, cell sorting
- Surface effects, Osmosis, Calorimetry, ITC
- Spectroscopy with light
- Radiation Biophysics, Spectroscopy with NMR and SPR
- Mass Spectrometry
- Electron Microscopy in life sciences
- AFM
- Interactions between particle beams and living matter (Light, X-rays, OCT), Free Electron Laser

Learning Prerequisites

Recommended courses

- Biophysics: physics of the cell (P. De Los Rios, S. Manley, BA6)
- Biophysics: physics of biological systems (S. Rahi, MA1)

Important concepts to start the course

- Thermodynamics, Fourier transformation

Learning Outcomes

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

• Describe the molecules and structural arrangement of modern biological cells
• Describe and quantitatively understand the physical mechanisms that drive living organisms.
• Explain the biophysical tools used to study the molecules of life and interpret their data.

Teaching methods

• 2 hours of class + 2 hour of exercises
• Students are invited to give one 10-min presentation on one of several possible topics during the semester.

Expected student activities

Homework will be given every week. Solutions will be handed out. Homework will not be graded. It is strongly advised to make the effort to do the homework weekly.

Assessment methods

• The course grading is composed of a final written exam
• Students should give a 10-min presentation on one of a given list of topics. Failure to give the presentation will lower the final grade by 0.5.

Resources

Bibliography

• David Sheehan: *Physical Biochemistry, Principles and Applications* (Wiley, 2013)

Ressources en bibliothèque

• Physical Biochemistry / Sheehan

Moodle Link

• https://go.epfl.ch/PHYS-468

PHYS-307

Physics of materials

La Grange Thomas

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

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

Summary

This course illustrates some selected chapters of materials physics needed to understand the mechanical and structural properties of solids. This course deals primarily with the physics of dislocation. The course also links diffusion kinetics to the fundamental physics of phase transformations.

Content

1. Materials, definitions, structure
Binding energy in metals, ceramics and polymers. Crystal structure and amorphous materials. Theory of elasticity: stress and strain fields.
2. Diffusion
Diffusion in alloys. Physical and chemical diffusion.
3. Plastic deformation and dislocations
Phenomenology. Deformation of single crystals. Burgers' vector. Elasticity theory: interactions among dislocations. Creation and annihilation of dislocations.
4. Dislocation dynamics
Friction forces due to the lattice, to point defects and to dislocations. Movement equations. Partial dislocations and stacking faults. Dissociation mechanisms: dislocations in face centred cubic metals.
5. Dislocation kinetics
Thermal activation of plastic deformation. Dislocation climb. Deformation tests. Relaxation phenomena and mechanical spectroscopy.
6. Thermodynamics of phase transformations
Thermodynamical principles of phase transformations.Phase diagrams. Alloy solidification. Solid-solid phase transformations.

Keywords

dislocations, deformation, diffusion, elasticity, phase transformations, melting, precipitation crystallography

Learning Prerequisites

Recommended courses

linear algebra I,II
analysis III, IV
physics I,II

Learning Outcomes

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

- Develop the formalism of dislocation theory

- Model the plastic deformation of materials
- Sketch a phase diagram and its thermodynamic basis

Transversal skills

- Use a work methodology appropriate to the task.
- Assess one's own level of skill acquisition, and plan their on-going learning goals.

Teaching methods

Oral Lectures and exercises in the classroom. Lecture, exercise and reference materials will be made available on a Moodle. A questions and answer forum is also available on the moodle. Additionally, zoom meeting or in-classroom session will be arranged for exam preperation

Assessment methods

Oral exam in English

Resources

Moodle Link

- https://go.epfl.ch/PHYS-307

Prerequisite for

Physics of new materials

EPFL

PHYS-434 **Physics of photonic semiconductor devices**

Grandjean Nicolas

Cursus	Sem.	Type
Electrical and Electronical Engineering	MA2, MA4	Opt.
Ing.-phys	MA2, MA4	Opt.
Microtechnics	MA2, MA4	Opt.
Minor in Quantum Science and Engineering	E	Opt.
Photonics minor	E	Opt.
Physicien	MA2, MA4	Opt.
Quantum Science and Engineering	MA2, MA4	Opt.

Language	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

Series of lectures covering the physics of quantum heterostructures (including quantum dots), microcavities and photonic crystal cavities as well as the properties of the main light emitting devices that are light-emitting diodes (LEDs) and laser diodes (LDs).

Content

1. Semiconductor materials for optoelectronics
2. Semiconducting nanostructures, microcavities and photonic crystals

• Quantum wells, superlattices, quantum dots and single photon emitters

• Basic features of microcavities and photonic crystals, Purcell effect, strong-coupling regime

4. Electroluminescence

• Light-emitting diodes, quasi-Fermi levels, emission spectra, efficiency, radiative and nonradiative lifetimes

• Applications: displays and solid-state lighting

5. Laser diodes

• Stimulated emission, material and modal gain, transparency and threshold currents, spectral characteristics, far-field and near-field emission patterns, efficiency, waveguides

• Fabry-Perot laser diodes, distributed feedback and vertical cavity surface emitting laser structures

• Bandgap engineering, quantum well laser diodes, separate confinement heterostructures

• Beyond conventional laser diodes: physics of high-ß nanolasers

Learning Prerequisites

Recommended courses

Semiconductor physics and light-matter interaction (Master)
Quantum physics I and II (Bachelor)
Solid State Physics I and II (Bachelor), Quantum Electrodynamics and Quantum Optics (Master)

Learning Outcomes

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

• Sketch - and explain the band diagram of quantum engineered heterostructures (quantum wells, superlattices,

quantum dots) subjected or not to an electric field
• Explain - the impact of the dimensionality of a semiconductor on excitonic properties
• Assess / Evaluate - the properties of single photon emitters and entangled photon sources made from semiconductor quantum dots
• Use - basic notions of quantum optics to classify light emitters: assessment of the coherence of a light-source via photon statistics (2nd-order correlation measurements)
• Explain - the origin of the enhancement of the spontaneous emission rate via the Purcell effect
• Assess / Evaluate - the performance of dielectric cavities (microcavities and photonic crystal slabs) in terms of quality factor and photon lifetime, Lambertian vs non-Lambertian light emission spectra
• Assess / Evaluate - the performance of LEDs: internal quantum efficiency, extraction efficiency, wall-plug efficiency, luminous efficiency, color rendering index of white light sources
• Link - the radiative and nonradiative carrier lifetimes to microscopic recombination paths in the framework of the ABC model (Shockley-Read-Hall, bimolecular recombination coefficient and Auger term)
• Explain - the operating behavior of light-emitting diodes and laser diodes by relying on rate equations
• Compute - the material gain of bulk semiconductors and quantum wells (notions of transparency and threshold currents, modal gain)
• Assess / Evaluate - the performance of laser diodes: output power, internal quantum efficiency, wall-plug efficiency
• Explain - the origin of the temporal coherence of laser diodes (narrow linewidth) and their modulation frequency (several Gbit/s for telecom applications)
• Distinguish - the main features of edge-emitting laser diodes and vertical cavity surface emitting lasers
• Assess / Evaluate - the performance of cavities (microcavities and photonic crystal slabs) in terms of quality factor and photon lifetime, Lambertian vs non-Lambertian light emission spectra

Transversal skills

• Use a work methodology appropriate to the task.
• Plan and carry out activities in a way which makes optimal use of available time and other resources.
• Communicate effectively with professionals from other disciplines.
• Take feedback (critique) and respond in an appropriate manner.
• Summarize an article or a technical report.
• Access and evaluate appropriate sources of information.
• Demonstrate a capacity for creativity.
• Demonstrate the capacity for critical thinking

Teaching methods

Ex cathedra with exercises

Expected student activities

Read the bibliographical ressources in order to fully integrate and properly use the physical concepts seen in the lectures and the exercices

Assessment methods

Oral exam

Supervision

Office hours	Yes
Assistants	Yes
Others	Office hours: appoinments to be arranged by email.

Resources

Bibliography

"Optoelectronics", E. Rosencher & B. Vinter (Cambridge University Press, Cambridge, 2002)
"Wave mechanics applied to semiconductor heterostructures", G. Bastard (Les éditions de physiques, Les Ulis, 1991)
"Optical processes in semiconductors", J. I. Pankove (Dover, New York, 1971)
"Diode lasers and photonic integrated circuits", L. A. Coldren & S. W. Corzine (John Wiley & Sons, Inc., New York, 1995)

Ressources en bibliothèque

- Optical processes in semiconductors / Pankove
- Diode lasers and photonic integrated circuits / Coldren
- Wave mechanics applied to semiconductor heterostructures / Bastard
- Optoelectronics / Rosencher

Moodle Link

- https://go.epfl.ch/PHYS-434

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
Hours	**5 weekly**
Lecture	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-424

Plasma II

Reimerdes Holger

Cursus	Sem.	Type
Energy minor	E	Opt.
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.

Language	English
Credits	6
Session	Summer
Semester	Spring
Exam	Oral
Workload	180h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

This course completes the knowledge in plasma physics that students have acquired in the previous two courses, with a discussion of different applications, in the fields of magnetic confinement and controlled fusion, astrophysical and space plasmas, and societal and industrial applications.

Content

A. Fusion energy

- Basics (nuclear reactions, the Lawson criterion)
- Magnetic Confinement: MHD model
- Magnetic Confinement: Tokamak equilibrium, instabilities and operational limits
- Magnetic Confinement: Transport - theoretical basis and phenomenology
- Magnetic Confinement: Heating, burning plasmas, ITER and route to a power plant

B. Industrial applications

- The basics of plasma discharges for industrial applications
- Examples of plasma applications in industry and medicine

C. Plasmas in nature

- Astrophysics and space plasmas
- Solar physics - radiation transport and dynamo
- Magnetic reconnection and particle acceleration

D. Plasma diagnostics

- Categories of plasma diagnostics
- Measurements of plasma properties, magnetic properties and processes at the plasma-material interface

Learning Prerequisites

Recommended courses

PHYS-324 Classical electrodynamics, PHYS-325 Introduction to plasma physics and PHYS-423 Plasma I.

Learning Outcomes

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

- Describe various applications of plasma physics
- Identify the main components and physics issues of magnetic confinement fusion
- Describe the main scientific issues in astrophysical plasmas
- Describe the main advantages of plasmas in industrial applications
- Describe the physics basis of key plasma diagnostics
- Work out / Determine when plasma effects are important

Teaching methods

Ex cathedra and exercises in class

Assessment methods

oral exam

Resources

Moodle Link

- https://go.epfl.ch/PHYS-424

EPFL

PHYS-421

Projet de Physique I

Profs divers *

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

Langue	français / anglais
Crédits	8
Retrait	Non autorisé
Session	Hiver
Semestre	Automne
Examen	Pendant le semestre
Charge	240h
Semaines	14
Heures	**8 hebdo**
TP	8 hebdo
Nombre de places	

Résumé

L'étudiant·e applique les compétences acquises au cours de ses études dans une recherche effectuée dans l'un des laboratoires de la section de physique sous l'encadrement d'un·e enseignant·e de la section. Elle/il est présent dans le laboratoire un jour par semaine.

Contenu

Objectifs d'apprentissage: Pour les Projets de Physique (TP IV) effectués à la Section de Physique les sujets traités peuvent être de la physique théorique, expérimentale ou appliquée.
Pour les Projets de Physique (TP IV) effectués dans une autre section de l'EPFL, un descriptif doit être fourni à l'adjoint du directeur de la Section pour lui permettre de prendre une décision quant à l'adéquation du sujet avec la formation de physicien·ne.

Mots-clés

physique appliquée, expérimentation, recherche

Acquis de formation

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

- Choisir ou sélectionner une méthode d'investigation
- Elaborer un projet de recherche
- Formuler une hypothèse
- Analyser des résultats expérimentaux
- Modéliser un système physique
- Exploiter des données
- Identifier les paramètres significatifs
- Représenter un modèle, un résultat expérimental
- Critiquer des hypothèses ou des résultats

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.
- Etre responsable de sa propre santé et sécurité au travail ainsi que de celles des autres.

- Gérer ses priorités.
- Persévérer dans la difficulté ou après un échec initial pour trouver une meilleure solution.
- Accéder aux sources d'informations appropriées et les évaluer.
- Ecrire un rapport scientifique ou technique.
- Ecrire une revue de la littérature qui établit l'état de l'art.

Méthode d'enseignement

Travail en laboratoire

Méthode d'évaluation

Un rapport écrit doit être fourni à la fin du travail
A written report must be provided at the end of the lab work

Ressources

Liens Moodle

- https://go.epfl.ch/PHYS-421

PHYS-641

Quantum Computing

Savona Vincenzo

Cursus	Sem.	Type
Ing.-phys	MA1, MA3	Opt.
Minor in Quantum Science and Engineering	H	Opt.
Physicien	MA1, MA3	Opt.
Physics		Opt.
Quantum Science and Engineering	MA1, MA3	Opt.

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

Frequency

Every year

Remark

Next time: Fall

Summary

After introducing the foundations of classical and quantum information theory, and quantum measurement, the course will address the theory and practice of digital quantum computing, covering fundamental and advanced topics such as recent quantum algorithms and the theory of quantum error correction.

Content

Introduction

- Crash course on quantum mechanics
- Quantum measurement and interaction with the environment
- Foundations of classical and quantum information theory

Quantum computing

- The quantum circuit model
- Universal quantum gates
- Quantum advantage and the Deutsch-Jozsa algorithm

Overview of quantum algorithms

- The quantum Fourier transform and Shor's factoring algorithm
- The quantum state amplification and Grover's database search algorithm
- The quantum phase estimation and linear system solving
- Digital quantum simulation and unitary time evolution
- The variational quantum eigensolver

Noise in quantum hardware and the digital noise model

Quantum error correction

- The Shor quantum error correction code
- Stabilizer codes

• Fault-tolerant quantum computing

Overview of recent advances in quantum hardware and software

Learning Prerequisites

Required courses

Quantum Physics I, Quantum Physics II

Resources

Bibliography

M. A. Nielsen & I. L. Chuang, Quantum Computation and Quantum Information (Cambridge, 2011)
John Preskill, Lecture Notes on Quantum Information and Computation

Moodle Link

• https://go.epfl.ch/PHYS-641

EPFL

PHYS-453

Quantum electrodynamics and quantum optics

Kippenberg Tobias

Cursus	Sem.	Type
Electrical and Electronical Engineering	MA1, MA3	Opt.
Ing.-phys	MA1, MA3	Opt.
Minor in Quantum Science and Engineering	H	Opt.
Photonics minor	H	Opt.
Physicien	MA1, MA3	Opt.
Quantum Science and Engineering	MA1, MA3	Opt.

Language	English
Credits	6
Session	Winter
Semester	Fall
Exam	Written
Workload	180h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

This course on one hand develops the quantum theory of electromagnetic radiation from the principles of quantum electrodynamics. It will cover basis historic developments (coherent states, squeezed states, quantum theory of spontaneous emission) and moreover modern developments, e.g. quantum noise.

Content

- **Coherent states, Quantization of a Harmonic Oscillator**
  - Quantization of the electromagnetic field, quantization of electrical circuits
  - Coherent states
  - Fock states
  - Squeezed states

- **Measuring the Quantum States of Light:**
  - Homodyne detection
  - Measurements, photon counting
  - Representations (Q-function, Wigner function, P-representation)

- **Photon correlations**
  - HBT effect, g(2) measurements

- **Strong coupling cavity QED.**
  - Light matter interaction, dipole approximation
  - Quantum description of a laser
  - Cavity QED Hamiltonian
  - Dispersive limit of cQED
  - Purcell effect

- **Applications of Cavity QED:**

- Generation of arbitrary quantum state of a Harmonic oscillator
- Quantum Metrology
- Dispersive regime of cavity QED, QND measurements of Two level systems (qubits)

- **Quantum Nondemolition measurements (QND)**
  - Quantum backaction in linear measurements
  - The standard quantum limit (SQL)
  - Backaction evading measurements (BAE)

- **Quantum theory of an amplifier**
  - QLE approach to negative temperature
  - Noise temperature and added photons
  - Phase sensitive and phase insensitive amplification processes

- **Degenerate OPO and Squeezed light generation.**
  - Parametric amplification and squeezing using second harmonic generation

- **Stochastic Schroedinger Equation and Measurement theory**
- Quantum Jumps, quantum trajectories

- **Other topics covered: Recent developments in quantum optics (quantum metrology, quantum communication, etc.), and use of Python Quantum Optical Toolbox to simulate open quantum systems**

Learning Prerequisites

Recommended courses

Quantum physics

Learning Outcomes

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

- Understand the quantum theory of electromagnetic radiation
- Understand the different effects of light-matter interaction
- Understand the differences of classical and quantum properties of light
- Use of Python toolbox to simulate open quantum systems
- Understand modern applications of quantum optics in quantum communication, quantum metrology and quantum computation

Teaching methods

Exercises (weekly).

Assessment methods

written exam

Resources

Moodle Link

- https://go.epfl.ch/PHYS-453

EPFL

PHYS-431 **Quantum field theory I**

Riva Francesco

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

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

Summary

The goal of the course is to introduce relativistic quantum field theory as the conceptual and mathematical framework describing fundamental interactions.

Content

This introductory course stresses the importance that quantum fields play in the description of relativistic particles, and vice versa.

The course starts with a quantum-field theoretical description of particles of spin-0, described by scalar fields; it focusses on:

- The notion of relativistic scalar field, introduced as a trivial representations of the Lorentz group
- Field dynamics, discussed first in classical field theory (e.g Noether theorem, action principle and Euler-Lagrange equations)
- Field quantization: Fock space, the existence of anti-particles, causality
- Perturbation theory, S-matrix, LSZ formalism, Feynman diagrams
- Applications to the computation of scattering and decay processes
- Introduction to Renormalization theory

Depending on time, the course will include other topics relevant for the description of spin-0 particles (e.g. Goldstone theorem and effective field theories)

Learning Prerequisites

Required courses

Classical Electrodynamics, Quantum Mechanics I and II, Analytical Mechanics, Mathematical Methods

Recommended courses

General Relativity and Quantum Mechanics III warmly recommended.

Learning Outcomes

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

- Expound the theory and its phenomenological consequences
- Formalize and solve the problems

Transversal skills

- Use a work methodology appropriate to the task.

Teaching methods

2 hours of the course will be given online (zoom)
1 hour course + exercices will be on site

Assessment methods

Oral, consisting of one theoretical question and one exercise, picked randomly and for which the candidate is allowed a 30 minute preparation

Resources

Bibliography

- "An introduction to quantum field theory / Michael E. Peskin, Daniel V. Schroeder". Année:1995. ISBN:0-201-50397-2
- "The quantum theory of fields / Steven Weinberg". Année:2005. ISBN:978-0-521-67053-1
- "Quantum field theory / Claude Itzykson, Jean-Bernard Zuber". Année:1980. ISBN:0-07-032071-3
- "Relativistic quantum mechanics / James D. Bjorken, Sidney D. Drell". Année:1964
- "A modern introduction to quantum field theory / Michele Maggiore". Année:2010. ISBN:978-0-19-852074-0

Ressources en bibliothèque

- An Introduction to Quantum Field Theory / Peskin
- The Quantum Theory of Fields / Weinberg
- A Modern Introduction to Quantum Field Theory / Maggiore
- Relativistic Quantum Mechanics / Drell
- Quantum Field Theory / Itzykson

Websites

- https://www.epfl.ch/labs/lptp/wp-content/uploads/2022/05/NewQFTLectureNotes.pdf

Moodle Link

- https://go.epfl.ch/PHYS-431

Prerequisite for

Recommended for Theoretical Physics and for Particle Physics

EPFL

PHYS-432

Quantum field theory II

Bellazzini Brando

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.

Language	English
Credits	6
Session	Summer
Semester	Spring
Exam	Oral
Workload	180h
Weeks	14
Hours	**5 weekly**
Lecture	3 weekly
Exercises	2 weekly
Number of positions	

Summary

The goal of the course is to introduce relativistic quantum field theory as the conceptual and mathematical framework describing fundamental interactions such as Quantum Electrodynamics.

Content

- Quantisation of fields and massive particles with spin and the relevance of symmetries in fundamental physics (Poincaré group, little groups, irreducible representations ...);
- Quantisation of massless particles with spin-1 (photons);
- Introduction to Quantum electrodynamics (QED);
- Discrete spacetime symmetries (P, C, T and CPT);
- Causality and statistics;
- Classical predictions of QED;
- Higher order calculations and quantum corrections.

Time permitting: more advanced topics such as the Higgs mechanism, electroweak interactions and non-abelian gauge theories, path integral...

Learning Prerequisites

Required courses

Classical Electrodynamics, Quantum Field Theory I, Quantum Mechanics I and II, Analytical Mechanics, Mathematical Physics

Recommended courses

Quantum Mechanics III and IV, General Relativity, Cosmology

Learning Outcomes

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

- Expound the theory and its phenomenological consequences
- Formalize and solve the problems

Transversal skills

- Use a work methodology appropriate to the task.

Teaching methods

Ex cathedra and exercises in class

Assessment methods

Exam: oral, consisting of one theoretical question and one exercise, picked randomly and for which the candidate is allowed a 45 minute preparation

Resources

Bibliography

- "An introduction to quantum field theory / Michael E. Peskin, Daniel V. Schroeder". Année:1995. ISBN:0-201-50397-2
- "The quantum theory of fields / Steven Weinberg". Année:2005. ISBN:978-0-521-67053-1
- Quantum Field Theory and the Standard Model / Matthew D. Schwartz". Année:2014. ISBN:1107034736
- Quantum Field Theory / Marc Srenedicki". Année:2007. ISBN:9780521864497
- "Quantum field theory / Claude Itzykson, Jean-Bernard Zuber". Année:1980. ISBN:0-07-032071-3
- "Relativistic quantum mechanics / James D. Bjorken, Sidney D. Drell". Année:1964
- "A modern introduction to quantum field theory / Michele Maggiore". Année:2010. ISBN:978-0-19-852074-0
- "Théorie quantique des champs / Jean-Pierre Derendinger". Année:2001. ISBN:2-88074-491-1

Ressources en bibliothèque

- Relativistic quantum mechanics / Bjorken
- Quantum field theory / Itzykson
- An introduction to quantum field theory / Peskin
- Quantum Field Theory / Srenedicki
- A modern introduction to quantum field theory / Maggiore
- The quantum theory of fields / Weinberg
- Quantum Field Theory and the Standard Model / Schwartz
- Théorie quantique des champs / Derendinger

Websites

- https://www.epfl.ch/labs/lptp/wp-content/uploads/2022/05/NewQFTLectureNotes.pdf

Moodle Link

- https://go.epfl.ch/PHYS-432

Prerequisite for

Prerequisite for Theoretical Physics

PHYS-425

Quantum physics III

Yazyev Oleg

Cursus	Sem.	Type
Ing.-phys	MA1, MA3	Opt.
Photonics minor	H	Opt.
Physicien	MA1, MA3	Opt.

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

Summary

To introduce several advanced topics in quantum physics, including semiclassical approximation, path integral, scattering theory, and relativistic quantum mechanics

Content

1. Transition from quantum physics to classical mechanics: the coherent states and the Ehrenfest theorem.

2. Semiclassical approximation in quantum mechanics: general form of the semiclassical wave function and matching conditions at turning points.

3. One-dimensional problems in semiclassical approximation: Bohr-Sommerfeld quantisation condition and the Planck formula, tunnelling probability through a potential barrier, lifetime of a metastable state, splitting of the energy levels in a double-well potential.

4. Path integral representation of quantum mechanics: Schrodinger equation from path integral, physical interpretation of the path integral and the principle of minimal action, Euclidean path integral and statistical physics, "instanton" and "bounce".

5. Scattering theory: cross-section, Moller operators and S-matrix, Green's functions and the scattering amplitude, the T-matrix and the Lippmann-Schwinger formula, perturbation theory for amplitudes and the Born approximation, scattering amplitude via stationary scattering states.

6. Relativistic quantum mechanics: the Dirac equation and its non-relativistic limit - the Pauli equation.

Learning Prerequisites

Required courses

Quantum physics I, II

Teaching methods

Ex cathedra and exercises

Assessment methods

oral exam (100%)

Supervision

Office hours	Yes

Resources

Bibliography

C. Cohen-Tannoudji, B. Diu, F. Laloe, Quantum Mechanics
L. D. Landau and E. M. Lifshitz, Quantum mechanics: non-relativistic theory
R. P. Feynman, A. R. Hibbs, Quantum Mechanics and Path Integrals
J. R. Taylor, Scattering Theory: The Quantum Theory of Nonrelativistic Collisions
J. D. Bjorken, S. D. Drell, Relativistic Quantum Mechanics
A. Messiah, Quantum Mechanics

Ressources en bibliothèque

- J. D. Bjorken, S. D. Drell, Relativistic Quantum Mechanics
- (Ebook) L. D. Landau and E. M. Lifshitz, Quantum mechanics: non-relativistic theory
- C. Cohen-Tannoudji, B. Diu, F. Laloe, Quantum Mechanics
- L. D. Landau and E. M. Lifshitz, Quantum mechanics: non-relativistic theory
- J. R. Taylor, Scattering Theory: The Quantum Theory of Nonrelativistic Collisions
- A. Messiah, Quantum Mechanics
- R. P. Feynman, A. R. Hibbs, Quantum Mechan

Moodle Link

- https://go.epfl.ch/PHYS-425

Prerequisite for

Quantum Physics IV

PHYS-426

Quantum physics IV

Penedones João Miguel

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.

Language	English
Credits	6
Session	Summer
Semester	Spring
Exam	Written
Workload	180h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

Introduction to the path integral formulation of quantum mechanics. Derivation of the perturbation expansion of Green's functions in terms of Feynman diagrams. Several applications will be presented, including non-perturbative effects, such as tunneling and instantons.

Content

1. Path Integral formalism

- Introduction
- Propagators and Green's functions.
- Fluctuation determinants.
- Quantum mechanics in imaginary time and statistical mechanics.

2. Perturbation theory

- Green's functions: definition and general properties
- Functional methods
- Perturbation theory by Feynman diagrams

3. Semiclassical approximation

- The semiclassical limit

4. Non perturbative effects

- Reflection and tunneling through a barrier
- Instantons

5. Interaction with external magnetic field

- Gauge invariance in quantum mechanics
- Landau levels
- Aharonov-Bohm effect
- Dirac's magnetic monopole and charge quantization.

Keywords

Path integral formalism. Green's function. Determinants. Feynman diagram. Feynman rules. Perturbation theory. Non-perturbative effects. Tunnelling. Instantons. Gauge-invariance.

Learning Prerequisites

Recommended courses

Quantum physics I, II and III
Quantum Field Theory I

Important concepts to start the course

Solid knowledge and practice of calculus (complex variable) and linear algebra

Learning Outcomes

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

- Formulate a quantum mechanical problem in terms of a Path integral
- Compute gaussian path integral as determinants
- Express physical quantities in terms of the Green function
- Translate a Feynman diagram into a mathematical expression
- Compute a Feynman diagram
- Compute tunneling rates in simple quantum potentials
- Formulate the quantum theory of a particle interacting with an external electromagnetic field

Transversal skills

- Use a work methodology appropriate to the task.
- Set objectives and design an action plan to reach those objectives.

Teaching methods

Ex cathedra and exercises

Expected student activities

Participation in lectures. Solving problem sets during exercise hours. Critical study of the material.

Assessment methods

Written exam

Supervision

Office hours	Yes
Assistants	Yes
Forum	Yes

Resources

Bibliography

"Quantum Mechanics and Path Integrals" , R.P. Feynman and A.R. Hibbs, McGraw-Hill, 1965.
"Techniques and applications of Path Integration", L.S. Schulman, John Wiley & Sons Inc., 1981.
"Path Integral Methods and Applications", R. MacKenzie, arXiv:quant-ph/0004090.
"Modern Quantum Mechanics", J.J. Sakurai, The Benjamin/Cummings Publishing Company, 1985.
"Aspects of Symmetry", S. Coleman, Cambridge University Press, 1985.

"Path Integrals in Quantum Mechanics, Statistics and Polymer Physics", Hagen Kleinert, World Scientific, 1995.

Ressources en bibliothèque

- Quantum Mechanics and Path Integrals
- Modern Quantum Mechanics
- Path Integrals in Quantum Mechanics, Statistics and Polymer Physics
- Path Integral Methods and Applications
- Techniques and applications of path integration
- Aspects of Symmetry

Notes/Handbook

Lecture Notes for Quantum Mechanics IV

Moodle Link

- https://go.epfl.ch/PHYS-426

EPFL

PHYS-462

Quantum transport in mesoscopic systems

Banerjee Mitali

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Minor in Quantum Science and Engineering	E	Opt.
Physicien	MA2, MA4	Opt.
Quantum Science and Engineering	MA2, MA4	Opt.

Language	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

This course will focus on the electron transport in semiconductors, with emphasis on the mesoscopic systems. The aim is to understand the transport of electrons in low dimensional systems, where even particles with statistics different than fermions and bosons will be discussed.

Content

1. Preliminary concepts in Condensed matter physics
2. Landauer-Buttiker formalism in one dimensional channel
3. IQHE, Basics, Classical Hall effect
4. FQHE, Review of IQHE
5. Berry Phase
6. Recent/Relevant experimental works in Graphene
7. Recent/Relevant advancements in the field

Learning Prerequisites

Required courses

Introduction to Solid state physics

Important concepts to start the course

Electronic transport, superconductivity

Learning Outcomes

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

- Develop basic understanding of quantum phenomenon in the mesoscopic devices and current state of the art experimental works in related fields

Assessment methods

oral exam during the exam session

Resources

Bibliography

Electronic transport in mesoscopic system by Supriyo Datta
and current research papers on related topics

Ressources en bibliothèque

- Electronic transport in mesoscopic system / Datta

Notes/Handbook

Lecture notes

Moodle Link

- https://go.epfl.ch/PHYS-462

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
Hours	**3 weekly**
Lecture	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
- 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
Hours	**3 weekly**
Lecture	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

- Radiation detection and measurement, Glenn F. Knoll
- Practical Gamma-Ray Spectrometry, Gordon R. Gilmore

Moodle Link

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

PHYS-427

Relativity and cosmology I

Penedones João Miguel

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

Language	English
Credits	6
Session	Winter
Semester	Fall
Exam	Written
Workload	180h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

Introduce the students to general relativity and its classical tests.

Content

Special Relativity (Review):

- Lorentz transformations
- Energy-momentum tensor

General relativity:

- Equivalence principle
- Tensor analysis and physics in curved space-time
- Einstein's equations
- Schwarzschild solution
- Classical tests of Einstein's theory
- Gravitational waves

Learning Prerequisites

Required courses

Analytical mechanics
Classical Electrodynamics

Important concepts to start the course

Special Relativity

Learning Outcomes

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

- Explain the basic concepts of special and general relativity
- Describe physical phenomena in different coordinate systems
- Compute Christofell symbols and curvatures from a given line element
- Solve Einstein's field equations for static spherically symmetric problems
- Explain the observational effects at the scale of the Solar System that cannot be described by Newtonian gravity

Teaching methods

Ex cathedra and exercices in classroom

Assessment methods

final written exam

Supervision

Office hours	Yes
Assistants	Yes
Forum	Yes

Resources

Bibliography

-

Ressources en bibliothèque

- Gravitation and Cosmology / Weinberg
- Gravitation / Mizner
- The classical theory of fields / Landau
- Spacetime and Geometry: an Introduction to General Relativity / Carroll
- A First Course in General Relativity / Schutz
- General relativity / Wald

Moodle Link

- https://go.epfl.ch/PHYS-427

PHYS-428

Relativity and cosmology II

Gorbenko Victor

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.

Language	English
Credits	6
Session	Summer
Semester	Spring
Exam	Written
Workload	180h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

This course is the basic introduction to modern cosmology. It introduces students to the main concepts and formalism of cosmology, the observational status of Hot Big Bang theory and discusses major physical processes in the early Universe.

Content

- Basic facts about the Universe
- Red shift and Hubble expansion
- Homogeneous spaces and Friedman-Robertson-Walker metric
- Open, closed and spatially flat universe
- Matter dominated and radiation dominated Universe
- Cosmological constant and accelerated universe expansion
- Physical processes in the early Universe and the cosmic microwave background radiation
- Inflationary cosmology

Keywords

1. Expansion of the Universe
2. Hot Big Bang theory
3. Dark matter
4. Accelerated expansion of the Universe
5. Inflation
6. Cosmic Microwave background radiation

Learning Prerequisites

Required courses

Analytical Mechanics
Classical Electrodynamics
Statistical Physics I
Relativity and Cosmology I

Recommended courses

Quantum Physics III
Relativistic quantum fields I
Nuclear and Particle Physics I, II

Learning Outcomes

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

- Estimate the lifetime of the Universe, knowing the cosmological parameters
- Formulate the main observational evidence for the hot Big Bang theory
- Describe basic cosmological epochs

Transversal skills

- Use a work methodology appropriate to the task.

Teaching methods

Ex cathedra and exercises

Assessment methods

final written exam 100%

Supervision

Office hours	Yes

Resources

Bibliography

1. L. Landau, Lifshitz, "The classical Theory of Fields"
2. S. Weinberg, "Gravitation and Cosmology"
3. E. Kolb, M. Turner, "The Early Universe"

Ressources en bibliothèque

- Gravitation and Cosmology / Weinberg
- The Early Universe / Kolb
- The classical Theory of Fields / Landau

Moodle Link

- https://go.epfl.ch/PHYS-428

EPFL

PHYS-400

Selected topics in nuclear and particle physics

Blanc Frédéric

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.

Language	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

This course presents the physical principles and the recent research developments on three topics of particle and nuclear physics: the physics of neutrinos, dark matter, and plasmas of quarks and gluons. An emphasis is given on experimental aspects in these three research fields.

Content

Neutrino physics:

- Neutrino mass measurements, beta and double-beta decay experiments.
- Neutrino mass generation mechanism, Majorana and Dirac particles.
- Neutrino oscillations, MNS matrix.
- Cosmic neutrinos : origin, energy spectrum and detection.

Dark matter:

- Evidence for dark matter from astronomical and cosmological data.
- Relic particles of the "Big bang". Candidates for dark matter, and link with particle physics beyond the Standard Model.
- Direct and indirect searches for dark matter.

Quark gluon plasma (QGP):

- Plasma of quarks and gluons: properties, plasma signatures, production in the collisions of heavy ions.

Learning Prerequisites

Required courses

Nuclear and particle physics I and II (PHYS-311, PHYS-312)

Recommended courses

Quantum physics I and II (PHYS-313, PHYS-314), Particle physics I (PHYS-415)

Learning Outcomes

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

- Interpret fundamental results in neutrino, dark matter, and quark and gluon plasma physics

- Identify the physical observables in these three fields of research
- Discuss the experimental principles in these fields
- Assess / Evaluate the experimental methods and results presented in scientific publications
- Estimate the experimental sensitivity of experiments

Teaching methods

Ex cathedra and exercises in the classroom

Assessment methods

oral exam (100%)

Supervision

Office hours	No
Assistants	Yes
Forum	Yes

Resources

Moodle Link

- https://go.epfl.ch/PHYS-400

PHYS-433

Semiconductor physics and light-matter interaction

Butté Raphaël

Cursus	Sem.	Type
Electrical and Electronical Engineering	MA1, MA3	Opt.
Ing.-phys	MA1, MA3	Opt.
Minor in Quantum Science and Engineering	H	Opt.
Photonics minor	H	Opt.
Physicien	MA1, MA3	Opt.
Quantum Science and Engineering	MA1, MA3	Opt.

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

Summary

Lectures on the fundamental aspects of semiconductor physics and the main properties of the p-n junction that is at the heart of devices like LEDs & laser diodes. The last part deals with light-matter interaction phenomena in bulk semiconductors such as absorption, spontaneous & stimulated emission.

Content

1. Electronic properties of semiconductors

- Crystalline structures and energy band diagrams
- Impurities and doping
- Carrier statistics in equilibrium and out-of-equilibrium
- Electron transport in weak and strong fields
- Generation and recombination processes

2. Theory of junctions and interfaces

- *p-n* and metal-semiconductor junctions
- Heterojunction interfaces

3. Light-matter interaction in semiconductors

- Fermi's golden rule, absorption, optical susceptibility, Bernard-Duraffourg condition (optical gain condition)
- Spontaneous and stimulated emission of radiation
- Dielectric function, optical constants
- Radiative lifetime, photoluminescence spectra

Learning Prerequisites

Recommended courses

Solid State Physics I and II (Bachelor), Quantum Electrodynamics and Quantum Optics (Master)
Quantum physics I and II (Bachelor)

Learning Outcomes

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

- Explain - the main electronic and optical properties of bulk semiconductors (band structure, doping, absorption, excitonic features) that are behind the first quantum revolution (transistors, LEDs and laser diodes)

- Identify - the main criteria governing the I-V characteristics of the p-n junction and explain its departure from ideality (role of defects and Joule heating)
- Classify - semiconductors depending on their doping level (non-degenerate vs degenerate semiconductors)
- Compute - the Shockley-Read-Hall term, the bimolecular recombination coefficient and the Auger term entering into the ABC model
- Compute - the absorption spectrum of direct bandgap bulk semiconductors
- Compute - the radiative lifetime of a 2-level system and that of a direct bandgap bulk semiconductor
- Explain - the main properties of tunnel diodes and solar cells

Transversal skills

- Give feedback (critique) in an appropriate fashion.
- Make an oral presentation.
- Demonstrate a capacity for creativity.
- Demonstrate the capacity for critical thinking
- Assess one's own level of skill acquisition, and plan their on-going learning goals.
- Summarize an article or a technical report.

Teaching methods

Ex cathedra with exercises

Expected student activities

Weekly graded homeworks to secure 1 point out of 6 (16.6% of the final grade)
Read the bibliographical ressources in order to fully integrate and properly use the physical concepts seen in the lectures and the exercices

Assessment methods

Written exam (with 1 point out of 6 earned via compulsory weekly homeworks (16.6%))

Supervision

Office hours	Yes
Assistants	Yes
Others	Office hours: appointments to be arranged by emails.

Resources

Bibliography

S. M. Sze, "Physics of semiconductor devices" 2nd edition (or > 2nd ed.) (John Whiley & Sons, New York, 1981)
P. Y. Yu and M. Cardona, "Fundamentals of Semiconductors, Physics and Materials Properties" 2nd edition (or > 2nd ed.) (Springer, Berlin, 1999)
N. W. Ashcroft and N. D. Mermin, "Solid State Physics" (Saunders College Publishing, Fort Worth, 1976)
E. Rosencher and B. Vinter, "Optoelectronics" (Cambridge University Press, Cambridge, 2002)

Ressources en bibliothèque

- E. Rosencher and B. Vinter, "Optoelectronics"
- N. W. Ashcroft and N. D. Mermin, "Solid State Physics" (Saunders College Publishing, Fort Worth, 1976)
- S. M. Sze, "Physics of semiconductor devices" 2nd edition (or > 2nd ed.) (John Whiley & Sons, New York, 1981)
- P. Y. Yu and M. Cardona, "Fundamentals of Semiconductors, Physics and Materials Properties" 2nd edition (or > 2nd

ed.) (Springer, Berlin, 1999)

Moodle Link

- https://go.epfl.ch/PHYS-433

PHYS-419

Solid state physics III

Läuchli Herzig Andreas Martin

Cursus	Sem.	Type
Ing.-phys	MA1, MA3	Opt.
Physicien	MA1, MA3	Opt.
Quantum Science and Engineering	MA1, MA3	Opt.

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

Summary

The aim of this course is to provide an introduction to the theory of a few remarkable phenomena of modern condensed matter physics ranging from the quantum Hall effects to superconductivity.

Content

Magnetism of insulators

- Review of band theory
- Mott insulators and Hubbard model
- Heisenberg model
- Spin-wave theory of ferromagnets and antiferromagnets

Orbital magnetism of metals and semiconductors

- Landau levels
- De Haas-Van Alphen and Shubnikov-de Haas oscillations
- 2D electron gas: Integer and fractional Quantum Hall effects

Theory of superconductivity

- Electron-phonon interaction
- BCS theory
- Landau-Ginsburg theory
- Flux quantization and Josephson effect

Learning Prerequisites

Recommended courses

Good grasp of quantum mechanics and solid state physics say at the level of *"Lectures on quantum mechanics"* by Gordon Baym and *"Solid state physics"* by Ashcroft and Mermin

Learning Outcomes

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

• Explore the quantum properties of solids and synthetic many body systems

Transversal skills

- Access and evaluate appropriate sources of information.
- Continue to work through difficulties or initial failure to find optimal solutions.

Teaching methods

Ex cathedra. Exercises in class

Assessment methods

oral exam

Resources

Bibliography

Lecture notes

Prerequisite for

Solid state physics IV

EPFL

PHYS-420

Solid state physics IV

Carbone Fabrizio

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.

Language	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

Solid State Physics IV provides a materials and experimental technique oriented introduction to the electronic and magnetic properties of strongly correlated electron systems. Established knowledge is complemented by current research trends, aiming to prepare the students for independent research.

Content

1. Brief Introduction to Scattering and spectroscopic methods
- Neutron scattering
- X-ray scattering
- Electron scattering
- Angular resolved photoemission and optical spectroscopy
- out of equilibrium experiments

2. Bulk methods
- Transport, specific heat and susceptibility

3. Strongly correlated electron materials
- Transition metal oxides
- Cuprates: high-temperature superconductivity
- manganites: colossal magnetoresistance

4. Introduction to quantum magnetism
- Low-dimensional magnetism
- Rare-earth magnetism
- Quantum phase transitions

Learning Prerequisites

Recommended courses

Solid state physics I and II or the equivalent to one of the book Aschroft & Mermin or Kittel

Learning Outcomes

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

- Decide which experimental technique is suited to investigate a certain phenomenon or property
- Interpret experimental data in the context of phenomena encountered during the course
- Sketch the key electronic and magnetic properties of transition metal material classes

Transversal skills

- Make an oral presentation.
- Summarize an article or a technical report.

Teaching methods

Lectures, exercises, visit to Paul Scherrer Institut

Assessment methods

oral exam (100%)

Resources

Ressources en bibliothèque

- Transition metal compounds / Khomskii

Websites

- http://lqm.epfl.ch/

Moodle Link

- https://go.epfl.ch/PHYS-420

EPFL

PHYS-464

Solid state systems for quantum information

Scarlino Pasquale

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Minor in Quantum Science and Engineering	E	Opt.
Physicien	MA2, MA4	Opt.
Quantum Science and Engineering	MA2, MA4	Opt.

Language	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

This course will give an overview of the experimental state of the art of quantum technology for Quantum Information Processing (QIP). We will explore some of the most promising approaches for realizing quantum hardware and critically assess each approach's strengths and weaknesses.

Content

We will provide a systematic introduction to experimental realizations of quantum information processing with solid-state systems, with a particular focus on the Superconducting Circuit Quantum Electrodynamics platform. We will explore the fundamentals of qubits, quantum gates, and measurements.
We will also introduce spin qubits defined by electrons and holes confined in a semiconductor environment. We will explain how we can isolate single electrons or holes in semiconducting islands called quantum dots and control them to perform quantum gates.
In addition, we will provide a thorough introduction to other physical implementations pursued in current research for realizing more robust solid-state qubits. We will also analyze hybrid devices implemented combining spin and mechanical degrees of freedom with superconducting technology on the same quantum device.

1. Introduction to Quantum Information Processing

- DiVincenzo criteria and universal quantum computers. Quantum gates, circuit representation. Example of algorithms.

2. Superconducting quantum hardware for quantum computing and QIP

- Understanding the physical concepts underlying superconducting qubits experiments: superconductivity and Josephson effect. Superconducting Quantum Interference Device. Quantization of electrical circuits.

3. Josephson junctions-based circuits.

- Cooper-pair box and Quantronium. Flux and Phase qubit. The transmon (limit) and its use as a quantum bit. Frequency tunability with SQUIDs. Fluxonium.

4. Measurement and Control of Superconducting qubits.

- Interfacing qubits and photons: circuit quantum electrodynamics (cQED). Design and fabrication of superconducting circuits and Experimental Setup for cQED experiments. Dispersive limit and readout of superconducting qubits. Characterizing qubit coherence.

5. Realizations of algorithms and protocols.

- Multiqubit devices: qubit/qubit interaction and entangling gates. Quantum Error Correction

6. Survey of other Physical Implementations for QIP: Electronic and nuclear spins in semiconductor quantum dots.

- Define Quantum Dots and Spin Qubits (Loss-Di Vincenzo, Singlet-Triplet, Exchange only,...) in GaAs, Si and Ge. Spin to Charge conversion readout. Electron spin manipulation. Two Spin qubits gates. Scaling up spin qubits.

7. Survey of other Physical Implementations for QIP: **Majorana fermions and Superconducting Protected qubits.**

8. Circuit Quantum Electrodynamics with Hybrid Systems.

- Coherent coupling of Superconducting systems to: Charge and Spin system in QDs, small ensembles of spins, mechanical systems. Electrically tunable Transmon (Gatemon).

Keywords

Quantum technology, quantum electrodynamics, quantum computing, quantum simulation, quantum optics, quantum measurement, quantum devices

Learning Prerequisites

Required courses

All students with a general interest in quantum information science, quantum optics, and quantum engineering are welcome to this course.
Basic knowledge of quantum physics and quantum systems concepts, e.g., from courses such as Quantum Physics I and II, or courses on topics such as atomic physics, solid-state physics, is a plus but not a strict requirement for successful participation in this course.

Recommended courses

Quantum Physics I, Quantum Physics II, Quantum Information and Quantum Computing

Important concepts to start the course

Superconductivity. Two-level system and harmonic oscillator in quantum mechanics.

Learning Outcomes

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

- Develop a basic understanding of the different elements necessary to build superconducting and semiconducting quantum circuits.
- Analyze and understand the scientific literature about the state-of-the-art of solid state quantum technology for quantum information.
- Establish conceptual insight into the operation, opportunities, and challenges of various qubit implementations.
- Work out / Determine the requirements of quantum hardware for quantum computing and quantum information technology.
- Compare various qubit implementations in different solid-state quantum platform.

Teaching methods

Ex-cathaedra, exercise classes. Mini-conference with student presentations.
In this course, lectures are combined with homework assignments as well as presentations of recent research papers.

Expected student activities

Weekly problem sheet solving, paper reading and presentation.

Assessment methods

Oral examination

Resources

Bibliography

Reviews and research papers to be studied at home, material presented during lectures.

For a review of the basics of Quantum Information and Computing:

• Quantum computation and quantum information / Michael A. Nielsen & Isaac L. Chuang. Reprinted. Cambridge: Cambridge University Press; 2001

For a review of superconducting quantum technology and circuit Quantum Electrodynamics:

• Girvin, S. M. (2011), Circuit QED: superconducting qubits coupled to microwave photons. Quantum machines: measurement and control of engineered quantum systems, 113, 2.

• P. Krantz, et al., A quantum engineer's guide to superconducting qubits, *Applied Physics Reviews* **6**, 021318 (2019); https://doi.org/10.1063/1.5089550

• Mahdi Naghiloo, Introduction to Experimental Quantum Measurement with Superconducting Qubits, *arXiv:1904.09291*

• A. Blais, A. L. Grimsmo, S.M. Girvin, and A. Wallraff, Circuit quantum electrodynamics, *Rev. Mod. Phys.* **93**, 025005 (2021).

For a review of semiconductor Spin Qubits:

• W. G. van der Wiel, S. De Franceschi, J. M. Elzerman, T. Fujisawa, S. Tarucha, and L. P. Kouwenhoven, Electron transport through double quantum dots, *Rev. Mod. Phys.* **75**, 1 (2002).

• R. Hanson, L. P. Kouwenhoven, J. R. Petta, S. Tarucha, and L. M. K. Vandersypen, Spins in few-electron quantum dots, *Rev. Mod. Phys.* **79**, 1217 (2007).

Ressources en bibliothèque

• Mahdi Naghiloo, Introduction to Experimental Quantum Measurement with Superconducting Qubits
• A.M. Zagoskin, Quantum engineering: theory and design of quantum coherent structures
• Girvin, S. M. (2011), Circuit QED: superconducting qubits coupled to microwave photons
• W. G. van der Wiel, S. De Franceschi, J. M. Elzerman, T. Fujisawa, S. Tarucha, and L. P. Kouwenhoven, Electron transport through double quantum dots
• R. Hanson, L. P. Kouwenhoven, J. R. Petta, S. Tarucha, and L. M. K. Vandersypen, Spins in few-electron quantum dots
• A. Blais, A. L. Grimsmo, S.M. Girvin, and A. Wallraff, Circuit quantum electrodynamics
• Quantum computation and quantum information / Michael A. Nielsen & Isaac L. Chuang
• P. Krantz, et al., A quantum engineer's guide to superconducting qubits

Moodle Link

• https://go.epfl.ch/PHYS-464

EPFL

PHYS-435 **Statistical physics III**

Wyart Matthieu

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

Language	English
Credits	6
Session	Winter
Semester	Fall
Exam	Written
Workload	180h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

This course introduces statistical field theory, and uses concepts related to phase transitions to discuss a variety of complex systems (random walks and polymers, disordered systems, combinatorial optimisation, information theory and error correcting codes).

Content

1. Introduction to statistical field theory
2. Random walks and self-avoiding polymers
3. Percolation, Networks
4. Information theory and error correcting codes
5. Disorded systems (spin glasses) and combinatorial complexity

Learning Prerequisites

Recommended courses

Statistical Physics II

Learning Outcomes

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

- Solve problems in complex systems

Transversal skills

- Assess one's own level of skill acquisition, and plan their on-going learning goals.

Teaching methods

Ex cathedra. Exercises in class

Assessment methods

written exam

Resources

Moodle Link

- https://go.epfl.ch/PHYS-435

EPFL

PHYS-436 **Statistical physics IV**

Kippenberg Tobias

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.
Quantum Science and Engineering	MA2, MA4	Opt.

Language	English
Credits	6
Session	Summer
Semester	Spring
Exam	Written
Workload	180h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

This first part of the course covers non-equilibrium statistical processes and the treatment of fluctuation dissipation relations by Einstein, Boltzmann and Kubo. Moreover, the fundamentals of Markov processes, stochastic differential and Fokker Planck equations, mesoscopic master equation, noise s

Content

I

I. Introduction to classical non-equilibrium thermodynamics

- Brownian Motion and Einstein relation
- Stochastic differential equation, Ito calculus and Fokker Planck equations
- Anomalous Diffusion, Levy Flights
- Metastabilty and Kramers escape rate problems
- Mesoscopic Master equation

II. Statistical Mechanics of Linear Response

- Kubo Formula
- Fluctuation Dissipation Theorem
- Markovian Processes
- Non-equilibrium Fluctuation theorems: Jarzinsky and Crook equality
- Metropolis Hastings algorithm for simulation of state space

III. Open Quantum Systems: stochastic methods in Quantum Optics

- The quantum Master equation and open quantum systems
- The damped quantum mechanical harmonic oscillator
- Two level system in a heat bath, de-phasing processes.
- Quantum stochastic Langevin equations
- Quantum optical master equation and numerical methods of solution (QuTip Python)
- Classical versus Quantum mechanical spectral densities

IV. Special topic (1 Week): Probabilistic data analysis. Metropolis Hastings / Monte Carlo Markov Chains Algorithm in Bayesian Statistical Analysis

- Applications of Markov Chain Monte Carlo (MCMC) to Bayesian Statistical analysis (using the EMCEE Python package). This has proven useful in too many research applications of which the Wilkinson Microwave Anisotropy Probe (WMAP) cosmology mission provide a dramatic example.

Additional Learning outcomes:

- program Jupyter notebooks based on Python to simulated Brownian motion, escape rate problems, etc.
- Utilize QuTip (quantum optical toolbox)
- Use EMCEE Monte Carlo Markov Chain for for Stat. Data analysis

Learning Prerequisites

Required courses

Quantum Optics advantageous

Recommended courses

Statistical physics I, II, III
Quantum Optics

Learning Outcomes

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

- Formulate correct mathematical models of statistical processes
- Solve succesfully the quantum master equation using QuTip in Python
- Apply numerical simulation tools to non-equilibrium systems
- Explore the quantum optical numerical Toolbox (MATLAB)
- Visualize non-equilibrium processes numerically using Jupyter Notebooks
- Elaborate modern examples from Literature of Non-Equilibrium Processes
- Apply EMCEE Python package to Bayesian statistical data analysis

Transversal skills

- Make an oral presentation.
- Summarize an article or a technical report.
- Take feedback (critique) and respond in an appropriate manner.
- Use both general and domain specific IT resources and tools

Teaching methods

Blackboard, summary slides and homeworks.

Expected student activities

Weekly graded homeworks for an extra point.

Assessment methods

Written exam (plus extra points via weekly homeworks)

Supervision

Assistants	Yes

Resources

Bibliography

- **Primary references:**
- Scientific Papers (e.g. Nonequilibrium Measurements of Free Energy Differences for Microscopically Reversible Markovian Systems, and many more)
- **Other references. Selected chapters of the books:**
- Risken H. The Fokker-Planck equation.. methods of solution and applications (2ed., Springer, 1989)(T)(485s)
- Gardiner - Handbook of stochastic methods (2ed., Springer, 1997)
- Markov Processes, Gillespie
- Statistical Methods in Quantum Optics 1 HJ Carrmichael
- Lévy statistics and laser cooling—Cambridge University Press
- Quantum Noise, Gardiner Zoller, Springer

Ressources en bibliothèque

- Quantum Noise
- Markov processes : an introduction for physical scientists
- Handbook of stochastic methods
- Lévy statistics and laser cooling
- The Fokker-Planck equation.. methods of solution and applications
- Statistical Methods in Quantum Optics 1 - Master Equations and Fokker-Planck Equations

Notes/Handbook

Moodle with Notes, papers, and bookchapters

Moodle Link

- https://go.epfl.ch/PHYS-436

EPFL

PHYS-441

Statistical physics of biomacromolecules

De Los Rios Paolo

Cursus	Sem.	Type
Ing.-phys	MA1, MA3	Opt.
Life Sciences Engineering	MA1, MA3	Opt.
Physicien	MA1, MA3	Opt.
Physics of living systems minor	H	Opt.
Physics		Opt.

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

Summary

Introduction to the application of the notions and methods of theoretical physics to problems in biology.

Content

1. Introduction to polymer theory: on and off-lattice polymers; statistical properties; exact, numerical and approximate results; correlation length; self-avoidance.
2. Interacting polymers: experiments and models; analytical and numerical solutions of the models; phase diagram.
3. Proteins: their role in biology; basic components; experimental results; models; analytical and numerical results.
4. Molecular Binding: Derivation of basic rules. Equilibrium and non-equilibrium binding.
5. Molecular Motors: how to use energy for directed motion.

Learning Prerequisites

Recommended courses

Course of Statistical Physics

Learning Outcomes

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

- Solve problems in polymers statistical physics

Transversal skills

- Assess one's own level of skill acquisition, and plan their on-going learning goals.

Teaching methods

Ex cathedra. Exercises in class

Assessment methods

oral

Resources

Moodle Link

- https://go.epfl.ch/PHYS-441

PHYS-512

Statistical physics of computation

Krzakala Florent, Zdeborová Lenka

Cursus	Sem.	Type
Computer science	MA1, MA3	Opt.
Cybersecurity	MA1, MA3	Opt.
Data Science	MA1, MA3	Opt.
Ing.-phys	MA1, MA3	Opt.
Physicien	MA1, MA3	Opt.
SC master EPFL	MA1, MA3	Opt.

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

Summary

This course covers the statistical physics approach to computer science problems ranging from graph theory and constraint satisfaction to inference and machine learning. In particular the replica and cavity methods, message passings algorithms, and analysis of the related phase transitions.

Content

Interest in the methods and concepts of statistical physics is rapidly growing in fields as diverse as theoretical computer science, probability theory, machine learning, discrete mathematics, optimization, signal processing and others. Large part of the related work has relied on the use of message-passing algorithms and their connection to the statistical physics of glasses and spin glasses.

This course covers this active interdisciplinary research landscape. Specifically, we will review the statistical physics approach to problems ranging from graph theory (e.g. community detection) to discrete optimization and constraint satisfaction (e.g. satisfiability or coloring) and to inference and machine learning problems (learning in neural networks, clustering of data and of networks, compressed sensing or sparse linear regression, low-rank matrix factorization).

We will expose theoretical methods of analysis (replica, cavity, ...) algorithms (message passing, spectral methods, etc), discuss concrete applications, highlight rigorous justifications as well as present the connection to the physics of glassy and disordered systems.

This is an advanced theoretical course that is designed for students with background in mathematics, electrical engineering, computer science or physics. This course exposes advaced theoretical concepts and methods, with exercises in the analytical methods and usage of the related algorithms.

Learning Prerequisites

Important concepts to start the course

For physics students Statistical physics I and II (or equivalent) is required.
This lecture is accessible to students in mathematics, electrical engineering, computer science without any previous training in statistical physics. Those students are expected to have strong interest in theory, probabilistic approaches to analysis of algoriths, high-dimensional statistics or probabilistic signal processing.

Learning Outcomes

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

- Analyze theoretically a range of problems in computer science and learning.
- Derive algorithms for a range of computational problems using technics stemming from statistical physics.

Teaching methods

2h of lecture + 2h of excercise

Assessment methods

Final written exam counting for 50% and several graded homeworks during the semester counting for the other 50%.

Resources

Bibliography

Information, Physics and Computation (Oxford Graduate Texts), 2009, M. Mézard, A. Montanari

Statistical Physics of inference: Thresholds and algorithms, Advances in Physics 65, 5 2016, L. Zdeborova & F. Krzakala, available at https://arxiv.org/abs/1511.02476

Ressources en bibliothèque

- Information, Physics and Computation / Mézard

Notes/Handbook

Policopié "Statistical Physics methods in Optimization & Machine Learning" by L. Zdeborova & F. Krzakala (available as pdf on the course website)

Moodle Link

- https://go.epfl.ch/PHYS-512

PHYS-466

Topics in biophysics and physical biology

Manley Suliana

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.

Language	English
Credits	3
Session	Summer
Semester	Spring
Exam	During the semester
Workload	90h
Weeks	14
Hours	**3 weekly**
Lecture	2 weekly
Exercises	1 weekly
Number of positions	

Summary

This course provides exposure to research in biophysics and physical biology, with emphasis on the nature of scientific breakthroughs, and using critical reading of scientific literature. Each week, we will discuss the research of one recipient of the Max Delbruck Prize in Biological Physics.

Content

What constitutes a scientific breakthrough? An outstanding contribution to a scientific field? We will examine these questions by delving into the research of several recipients of the Max Delbruck Prize in Biological Physics, awarded bi-annually/annually by the American Physical Society. Course materials include video lectures by the prize recipients, as well as scientific literature. Students will have the opportunity to analyze, synthesize, and present synopses of chosen areas in Biological Physics.

Learning Outcomes

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

- Discuss
- Reason
- Argue
- Present
- Synthesize
- Analyze

Transversal skills

- Access and evaluate appropriate sources of information.
- Make an oral presentation.
- Summarize an article or a technical report.
- Write a literature review which assesses the state of the art.

Assessment methods

Continuous assessment includes quizzes, and oral and written contributions from students.

Resources

Moodle Link

- https://go.epfl.ch/PHYS-466

EPFL

PHYS-597

Travail de spécialisation pour master en physique

Profs divers *

Cursus	Sem.	Type
Physicien	MA1, MA3	Opt.

Langue	français / anglais
Crédits	30
Session	Hiver
Semestre	Automne
Examen	Pendant le semestre
Charge	900h
Semaines	
Heures	**680 hebdo**
TP	680 hebdo
Nombre de places	

Remarque

Durée du travail de spécialisation interne : un semestre - Durée du travail de spécialisation externe: min. 4 mois, max. 6 mois / Duration of a internal specialisation semester (EPFL): one semester. E

Résumé

Students have the opportunity to apply their knowledge in a project contributing to specialize them in a physics field. The project can take place in a laboratory at EPFL, in an external laboratory or in a research institute.

Contenu

Students develop a physics-related project that allows them to acquire new knowledge and practical experience in a specific fiels under the supervision of a professor from Physics section. The person in charge of the work may ask the student to obtain specific training.
Doctoral courses could be required for some labs. Information here:
https://epfl.ch/schools/sb/sph/en/master/master-in-physics/specialization-semester
Credits for the specialization semester are awarded based on the evaluation of the specialization work. There are no credits assigned for courses taken in the specilalization semester.

Acquis de formation

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

- Développer un problème de physique complexe
- Défendre une solution
- Synthétiser la démarche pour solutionner le problème
- Modéliser un système ou un processus
- Appliquer des compétences à un concept ou une solution technique

Compétences transversales

- Comparer l'état des réalisations avec le plan et l'adapter en conséquence.
- Etre conscient et respecter les règles de l'institution dans laquelle vous travaillez.
- Gérer ses priorités.
- Ecrire un rapport scientifique ou technique.
- Communiquer efficacement et être compris y compris par des personnes de languages et cultures différentes.
- Recueillir des données.
- Accéder aux sources d'informations appropriées et les évaluer.

Méthode d'évaluation

Written report and oral presentation to relevant staff and to the supervisor.