

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

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

## 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
- Metastability 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 successfully 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 Carmichael
- 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>