PHYS-436 **Statistical physics IV**

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

Summary

Noise and fluctuations play a crucial role in science and technology. This course treats stochastic methods, applying them to both classical problems and quantum systems. It emphasizes the frameworks of fluctuation-dissipation theorems, stochastic differential equations, and Markov processes.

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

The teaching approach combines classical blackboard lectures and homework exercises with modern active learning techniques: topical research paper presentations and numerical simulations of the studied equations. In addition, we provide video recordings and summary slides for each lecture.

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

• Statistical Methods in Quantum Optics 1 - Master Equations and Fokker-Planck Equations

• Lévy statistics and laser cooling

• The Fokker-Planck equation.. methods of solution and applications

• Handbook of stochastic methods

Notes/Handbook

Moodle with Notes, papers, and bookchapters

Moodle Link

• https://go.epfl.ch/PHYS-436