

PHYS-744

**Advanced Topics in Quantum Sciences and Technologies**

Brantut Jean-Philippe, Galland Christophe, Savona Vincenzo, Various lecturers

| Cursus  | Sem. | Type |
|---------|------|------|
| Physics |      | Opt. |

|                            |                   |
|----------------------------|-------------------|
| Language of teaching       | English           |
| Credits                    | 4                 |
| Session                    |                   |
| Exam                       | Oral presentation |
| Workload                   | 120h              |
| <b>Hours</b>               | <b>56</b>         |
| Courses                    | 32                |
| Exercises                  | 24                |
| <b>Number of positions</b> |                   |

**Frequency**

Every 2 years

**Remark**

Next time: Fall 2020

**Summary**

This course provides an in-depth treatment of the latest experimental and theoretical topics in quantum sciences and technologies, with a focus on quantum sensing, quantum optics, cold atoms, and the theory of quantum measurements and open dissipative quantum systems.

**Content****V. Savona : Introduction to the theory of open quantum systems.**

1. The quantum master equation of a system coupled to a Markovian environment. General and microscopic derivations.
2. Stochastic unravelings: quantum trajectories and continuous homodyne measurement.
3. Examples of application: the damped harmonic oscillator, phase noise, dissipative state engineering, noisy quantum channels, hands-on efficient numerical implementations.

**C. Galland : Fundamentals of quantum sensing and its experimental realization with solid-state spins.**

1. Quantum description of two-level systems and their interaction with electromagnetic fields (incl. reminders from QO I and II). Bloch sphere, pulsed interactions in the rotating frame.
2. Electron spin resonance spectroscopy with continuous and pulsed RF and microwave fields. Basics of nuclear magnetic resonance.
3. Introduction to solid state spin qubits - focus on the negatively charged nitrogen vacancy center in diamond: electronic and spin states, hyperfine structure, optical properties, excited state and spin dynamics.
4. Experimental realisations of quantum sensing with NV centers: sensing magnetic fields, electric fields, temperature, strain, etc. Spin noise spectroscopy and its applications in condensed matter physics and biology.
5. Diamond micro- and nano-fabrication techniques for diamond photonics. Practical considerations about instrumentation for quantum sensing.

**JP Brantut : Quantum simulation with ultracold atoms**

1. General framework of quantum simulation, effective low-energy models
2. Atom-atom interactions, Feshbach resonances
3. The BEC-BCS crossover, Tan's relations
4. Optical lattices, superfluid to Mott insulator quantum phase transition

Foreseen evaluation procedure: A one- or half-day mini-symposium will be organised, in which each student will be presenting one of the proposed papers. Some pre-established (and spontaneous) questions will be asked by the three EPFL lecturers. Grades will be granted according to the quality of the understanding demonstrated during the presentation and the answers to the questions. Questions asked by the students will also be encouraged and valued.

**Keywords**

Quantum Science, Quantum Technology, Quantum sensing, Quantum Optics; Quantum simulation; Quantum measurement; Open systems; Cold atoms; Cavity optomechanics; Single photon detection

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

Required : Quantum Optics I and II

Recommended : Statistical Physics IV

**Learning Outcomes**

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

- to understand current research in the field of quantum science and technology
- to understand the challenges in experimental implementation of QST and be familiar with the theoretical tools used to describe real quantum systems

**Expected student activities**

To understand current research in the field of quantum science and technology; to understand the challenges in experimental implementation of QST and be familiar with the theoretical tools used to describe real quantum systems.

**Resources****Notes/Handbook**

Advanced Topics in Quantum Sciences and Technologies is a graduate-level lecture series dedicated to PhD and Master students already possessing a background in quantum mechanics and quantum optics. Invited lecturers: Patrick Maletinsky (Uni Basel), Christian Degen (ETHZ), Philipp Treutlein (Uni Basel), Mayeul Chipaux (EPFL), Marco Genovese (Torino)