Ultrafast phenomena
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Summary
The course will cover fundamental concepts and recent developments in the field of ultrafast spectroscopy and introduce the basic theory to understand ultrafast (10-16 - 10-9 s) phenomena in chemistry, biology and condensed matter physics.

Content
For the study of electronic and structural dynamics in solids and (bio-) molecules in “real” time, a variety of time-resolved spectroscopic techniques (in the optical, THz, and X-ray region of the electromagnetic spectrum, as well as using short electron pulses) are available.

The fastest dynamics that are accessible with state-of-the-art experiments are the motion of electrons in the attosecond regime (10-18-10-16 s), vibrational motion of molecules (10-14 s), and electronic relaxation pathways (>10-12 s). Examples include the breaking of interatomic bonds, vibrational dynamics in molecular systems, tracking of radiative and non-radiative electron relaxation pathways in biological systems, as well as charge carriers dynamics in materials.

The course addresses technological and theoretical aspects, and in the last part a few examples from literature will be studied:

1. Principles of femtosecond laser system
   - Overview of laser oscillators and pulse amplification
   - Parametric generation and amplification
   - Pulse measurement/characterization.

2. Time-resolved spectroscopy methods
   - Transient absorption (pump-probe) spectroscopy and fluorescence up-conversion
   - Non-linear optical methods (4-wave mixing, photon echo, transient grating and multidimensional spectroscopies)
   - Time-resolved core-level spectroscopies (X-ray absorption, emission, photoelectron spectroscopy, etc.) using synchrotron and XFEL radiation, as well as table-top High Harmonic Generation (HHG) sources.
   - Electron-based methods (scattering, crystallography, microscopy, spectroscopy)

3. Theory (no, or minimal, pre-existing knowledge is required)
   - Non-linear optics
   - Density matrix formalism
   - Liouville-space pathways
• Correlation functions

4. Examples: Photon-Echo spectroscopy, Biological electron an energy transfer, Solvation dynamics, charge carriers in materials, etc....

Students are encouraged to bring up subjects/papers for discussion.

Keywords
Picosecond, femtosecond, attosecond, chemistry, biology, materials, spectroscopy, pump-probe, Nonlinear optics, X-rays, electrons, pulsed X-ray sources (synchrotrons, X-ray free electron lasers), ultrashort electron pulses.

Learning Prerequisites
Required courses
Quantum mechanics
Molecular Physics-Condensed matter physics-physical chemistry

Expected student activities
Read an article in ultrafast science and formulate his/her own questions

Resources
Ressources en bibliothèque
• Saleh & Teich â## Fundamentals of Photonics
• Minhaeng Cho â## Two dimensional optical spectroscopy
• Ultrafast Dynamics in Molecules, Nanostructures and Interfaces
• Peter Hamm â## Mukamel for dummies