CHEMISTRY - CHM 6180

LASERS IN CHEMISTRY
Fall 2023

(Laser Spectroscopy, with applications to chemistry, chemical analysis and physical diagnostics of atomic and molecular systems)

Class times: M,W,F 12:50 PM - 13:40 PM (6^{th} Period) – Location: FLI 109
Instructor: Prof. Nicoló Omenetto **e-mail**: omenetto@chem.ufl.edu
Office: CLB 200A; Phone: 392-9853; Office hours: CLB 200A, Tuesday, Thursday: 8^{th} – 9^{th} period (2:00PM – 4:00PM) or by appointment.

1. Course objectives.

This course will lay the foundations of the interaction between the laser radiation and atomic and molecular systems. The purpose is to provide the analytical background necessary to understand "why" lasers are unique sources of radiation, "where" they can be used, and "when" should be used. Different types of lasers (solid, liquid and gas), modes of operation (Q-switching and mode locking), laser characteristic parameters such as wavelength coverage, temporal coherence (spectral bandwidth), spatial coherence, photon irradiance and fluence, and non-linear effects (frequency conversion and mixing) will be discussed in detail. The course will finally cover the basic principles and analytical applications of the most popular spectroscopic techniques (e.g., single and multi-photon absorption, emission, fluorescence, ionization, Raman and scattering methods) using lasers as primary excitation sources.

2. Textbook.

No textbook suggested for this class. Handout notes covering all the material covered in class will be distributed.

3. Material covered and planned weekly schedule.

Section I

- Lasers and their properties. Electromagnetic waves. Cavity and cavity modes. "Thermal" and laser radiation. Einstein coefficients. Temporal and spatial coherence. Laser bandwidth (broad band versus monochromatic radiation). Single mode and multi-mode emission. Laser irradiance and diffraction limited radiation.

- Theoretical basis of absorption, emission and fluorescence. Width of spectral lines. Homogeneous and inhomogeneous broadening (Doppler, collision, power and transit time broadening). Lorentz classical electron oscillator model. Oscillator strength. Linear (single-photon) and Non-linear (Multi-photon) absorption. Saturation effects. Hole burning. High-resolution (Doppler-free) spectroscopy.
- Laser oscillation. Threshold and Gain. Gain saturation. Small-signal gain and laser output.

Section II

- Different types of lasers and their operational characteristics. 3- and 4-level laser systems. Solid state lasers. Gas lasers. Excimer lasers. Dye lasers. Semiconductor lasers. Free electron lasers. Q-switching and Mode-locking operation of lasers. Propagation of laser beams (Gaussian beams). Spatial structure and Beam Quality parameters (TEM-modes).

Section III

- Essential outline of the description of atomic and molecular systems. Levels and transitions. Introduction to the quantum mechanical treatment of the interaction between atoms, molecules and radiation (stationary and time-dependent Schrödinger equations). Transition moments and spectroscopic selection rules. Effects of high intensity coherent pumping (e.g., Rabi oscillations and level splitting).

Section IV

This section should provide the link between the unique characteristics of lasers and their use in different fields of applied and fundamental research.

- Analytical Laser Spectroscopy. Basic principles of selected analytical methods. Atomic and molecular absorption. Atomic and molecular fluorescence. Time resolved fluorescence. Laser-ablation and Laser-induced Breakdown emission spectroscopy. Ionization techniques. Laser Photochemistry and Photo-fragmentation. Scattering methods (Raman spectroscopy and the definition and *meaning* of the *virtual level*).
- Diagnostics of plasmas with laser radiation. Time resolved spectroscopy. Pump and probe methods. Ultimate sensitivity and resolution achievable. Towards *absolute analysis* by laser methods.

4. Tests and Grading

Selected numerical problems from various book chapers will be given and discussed in class or during office hours. *As a preparation for the tests, typical problems/questions, including their solutions, will also be provided.*
There will be *1 Mid-term Test*, and a *Final Test*. Mid-term Test 1 will include the material covered in Section I and II, and the Final Test will cover Sections III and IV. *Tentative* dates for the exams are planned as follows:
Mid-term Test: Monday; October 11, 2023; Time: TBA.
Final Test: Date, time: Friday, December 15, 2023; Time: 10AM-12PM.

Grading will be based on a 200 points total and on a point distribution as follows: 1/2, 1/2. *See Table on page 4* for the correspondence between points and letter grades. Note that, *for the Mid-term Test*, *individual discussions of the results with the students will be organized.*

5. Policy related to class attendance, class demeanor and make-up exams

Participation in our class is fundamental since improving oral conversation skills is a key objective of the course.
Students are expected to attend 85% of the course. Punctuality is recommended. Cell phones should be silent during class time.
If justified, *late Mid-term exam can be considered*, with no additional penalty if taken within the next two days of the actual date of the exam. This may not be applicable to the Final test.
Students are expected to provide feedback on the quality of the instruction in this course by completing on-line evaluations at https://evaluations.ufl.edu. Evaluations are open two or three weeks before the end of the semester.

6. Miscellaneous

Students are referred to the instructions given in the University of Florida website regarding the University's honesty Policy (http://www.dso.ufl.edu/sccr/process/student-conduct-honor-code/), as well as phone numbers and contact sites for university counseling and mental health services.

CORRESPONDENCE POINTS - LETTER GRADES

≥170	A
160-169	A-
150-159	B+
140-149	B
130-139	B-
120-129	C+
100-119	C
< 100	C-