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General information	
Academic subject	***Physics of Sensors and Laboratory of Spectroscopy***
Degree course	*LM-17 Physics*
Academic Year	*2021-2022*
European Credit Transfer and Accumulation System (ECTS)	6
Language	*English*
Academic calendar (starting and ending date)	*2nd year, 1st Semester*
Attendance	*No*

Professor/ Lecturer	
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Department and address	*Physics Department – 2nd Floor – Room 233*
Virtual headquarters	
Tutoring (time and day)	Monday 03:00-05:00 pm Wednesday 03:00-05:00 pm

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Syllabus	
Learning Objectives	• Knowledge and understanding of phenomena related to light-matter interaction with quantum models and/or semiclassical approach. • Knowledge of state-of-the-art spectroscopic techniques and related optical components in a wide spectral range, from ultraviolet to far infrared. • Skills to work with advanced experimental equipment in an infrared spectroscopy laboratory • Competence to perform extended experimental investigations and critical analyses of the data, in order to write scientific reports.
Course prerequisites	Background knowledge on quantum mechanics, statistical physic and basic optics.
Contents	**Absorption and Emission of Light**. Discrete and Continuous Absorption and Emission Spectra. Transition Probabilities. Lifetimes. Spontaneous and Radiationless Transitions. Semiclassical Description. Basic Equations. Weak-Field Approximation. Transition Probabilities with Broad-band Excitation. Phenomenological Inclusion of Decay Phenomena. Problems. **Widths and Profiles of Spectral Lines**. Natural Linewidth. Lorentzian Line Profile of the Emitted Radiation. Relation between Linewidth and Lifetime. Natural Linewidth of Absorbing Transitions. Doppler Width. Collision Broadening of Spectral Lines. Phenomenological Description. Theoretical Treatment of Anelastic Collisions. Saturation Broadening. Problems. **Roto-Vibrational Spectroscopy.** The Born-Oppenheimer Approximation. Rotational Spectroscopy. The rigid rotor. Linear Rotor. Transition Frequencies. Selection Rules. Intensity. Centrifugal Distortion. Symmetric Rotor Molecules. Prolate. Oblate. Spherical Rotor Molecules. Asymmetric Rotor Molecules. Vibrational Spectroscopy. The Harmonic Oscillator. Infrared Spectra. Electrical and Mechanical Anharmonicity. Roto-Vibrational Spectroscopy. P- R- and Q-branch. Branches Asymmetry. Polyatomic Molecules. Normal modes of vibrations. Group Vibrations. Basics on HITRAN Database. Example: Fundamental Band of Carbon Monoxide Molecule.

	Spectroscopic Instrumentations. Spectrographs and Monochromators. Figures of Merit. Speed of Spectrometer. Spectral Transmission. Spectral Resolving Power. Free Spectral Range. Prims Spectrometer. Grating Spectrometer. Interferometers. Basic Concepts. Michelson Interferometer. Mach-Zehnder Interferometer. Multiple-Beam Interference. Fabry-Perot Interferometer. Multilayer Dielectric Coatings. Problems. **Doppler-Limited Absorption Laser Spectroscopic Techniques**. Advantages of Laser Spectroscopy. Direct Absorption Spectroscopy. Modulation Techniques. Amplitude Modulation. Wavelength Modulation. Lock-in detection. Multipass Cell Absorption Spectroscopy. White Multipass Cell. Herriott Multipass Cell. Cavity Enhanced Absorption Spectroscopy. Longitudinal TEM00 cavity modes. Finesse and spectral bandwidth. Mode matching of the laser beam to the cavity. Cavity Ring-Down Absorption spectroscopy. Photoacoustic Spectroscopy. Light absorption and heat generation. Sound wave generation and detection. Quartz-enhanced photoacoustic spectroscopy. Quartz tuning forks: flexural modes. Pressure influence on damping and natural frequencies. Comparison of different gas detection techniques. Minimum absorption coefficient. Normalized noise equivalent absorption. **Physics of Sensors**. Sensor Characteristics. Transfer Function and Dynamic Range. Accuracy. Hysteresis. Saturation. Repeatability. Resolution. Dynamic Characteristics. Reliability. Calibration of a gas sensor. Physical Principles of Sensing. Piezoelectric Effect. Pyroelectric Effect. Seebeck Effect. Peltier Effect. **How to Prepare a Scientific Paper**. Overview. Structure and organization of a scientific paper. Introduction. Method. Results and discussion. Conclusions. Abstract. Scientific Style. Basics on Data Analysis with OriginLab. **Laboratory Activities**. Light-Current-Voltage Characterization of a Quantum Cascade Laser. Spectral Characterization of a Quantum Cascade Laser by using a FT-IR. Direct Absorption Spectroscopy. Wavelength Modulation Spectroscopy. Quartz-Enhanced Photoacoustic Spectroscopy.
Books and bibliography	W. Demtroder – Laser Spectroscopy – Basic Concepts and Instrumentation, Springer. J. Fraden – Handbook of Modern Sensors – Physics Designs and Applications, Springer.
Additional materials	

Work schedule			
Total	Lectures	Hands on (Laboratory, working groups, seminars, field trips)	Out-of-class study hours/ Self-study hours
Hours			
150	32	30	88
ECTS			
6	4	2	
Teaching strategy			

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Expected learning outcomes	
Knowledge and understanding on:	The student will be able to account for spectroscopic methods in different energy intervals, be able to describe the most common components in spectroscopic equipment, be able to discuss phenomena related to light-matter interaction in quantum mechanics.
Applying knowledge and understanding on:	The student will use the know-how acquired during the lectures to work with state-of-the-art instrumentations in an infrared spectroscopy laboratory for trace gas detection in the atmosphere. In this context, the student will realize a spectroscopy setup, acquire data and make a critical analysis of data. Then, the student will prepare a scientific paper in a format and with a style typically required by the scientific literature.
Soft skills	• *Making informed judgments and choices* o Address and discuss problems in the field of laser spectroscopy o Compare different spectroscopic techniques by properly selecting the figures of merit o Working with optical instruments and laser sources • *Communicating knowledge and understanding* o Capability to deepen research topics in the state of the art of scientific literature o Knowledge of the experimental methodologies and discuss the scientific results. • *Capacities to continue learning* o Capability to work in a small group for a common project and to present the results in the form of a scientific document.

Assessment and feedback	
Methods of assessment	Written report (30%), oral exam (70%)
Evaluation criteria	• *Adequate comprehension and global knowledge of concepts and arguments described throughout the course.* • *Discussion on the scientific report in a critical way, arguing all steps made during the laboratory activities.*
Criteria for assessment and attribution of the final mark	• 30 cum laude: complete, in-depth and critical knowledge of the topics, excellent language skills, full capability to apply knowledge to solve the proposed problems, excellent discussion on the scientific report; • 28 - 30: complete and in-depth knowledge of the topics, excellent language properties, able to apply knowledge to solve the proposed problems, excellent discussion on the scientific report; • 24 - 27: good knowledge of the topics, good language skills, good ability to apply most of the knowledge to solve the proposed problems, good discussion on the scientific report; • 20 - 23: adequate knowledge of the topics but limited mastery of the same, satisfactory language properties, more than sufficient ability to apply knowledge to solve the proposed problems, satisfactory discussion on the scientific report; • 18 - 19: basic knowledge of the main topics, basic knowledge of technical language, sufficient ability to apply the acquired basic knowledge, poor discussion on the scientific report; • <18 Insufficient: the knowledge of the topics covered during the course is not acceptable, the scientific paper is not acceptable.
Additional information	

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