COURSE OF STUDY *Physics (LM-17)*

ACADEMIC YEAR *2024-2025*

ACADEMIC SUBJECT *Physics of Sensors and Laboratory of Spectroscopy*

General information	
Year of the course	2nd
Academic calendar (starting and ending date)	1st semester: September - December 2024
Credits (CFU/ECTS):	6
SSD	FIS/03
Language	English
Mode of attendance	Compulsory

Professor/ Lecturer	
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Department and address	Physics Department, via Amendola 173
Virtual room	
Office Hours (and modalities: e.g., by appointment, on line, etc.)	Monday, 15:00 – 17:00; Wednesday, 16:00 – 18:00

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

Learning Objectives	Capability to understand the phenomena related to the absorption and emission of light. Ability to analyze infrared absorption spectra. Acquire theoretical and practical knowledge on cutting-edge techniques related to laser spectroscopy and its application in the field of advanced gas sensing.
Course prerequisites	Background knowledge on quantum mechanics, statistical physics, and basic optics.

Teaching strategies	Lectures in the teaching room with the aid of a laptop and a projector. Laboratory activities supervised.
Expected learning outcomes in terms of	
Knowledge and understanding on:	The student will be able to: o understand the scientific method, the nature, and the methods of research in Physics o acquire knowledge of the technologies required in experimental physics o acquire knowledge of advanced instrumentation in experimental physics o acquire knowledge related to the structure of matter, with particular attention to condensed matter and photonics applications o acquire knowledge of spectroscopic methods in different energy ranges o account for spectroscopic methods in different energy intervals.

	o acquire basic knowledge about the fundamental processes associated with laser spectroscopy o describe the most important laser spectroscopic methods and their applications in gas sensing
Applying knowledge and understanding on:	o identify the essential elements of a phenomenon o use analogy to apply known solutions to new problems (problem solving) o design and implement experimental or theoretical procedures to solve problems in academic and industrial research or to improve existing results o use analytical and numerical mathematical computation tools o apply basic principles of laser spectroscopic techniques for sensing o acquire practical skills to work with advanced experimental equipment in laboratory o perform extended experimental investigations and critically analyses of the acquired data o write proper scientific reports.
Soft skills	● **Making judgments and choices** Given a specific problem and project in the field of optical measurements, students will be able to: o work with increasing levels of autonomy, including taking responsibility in project planning and managing facilities o analyse the properties of the laser spectroscopy techniques and solve related problems, o correlate the laser properties with the spectroscopic technique o compare autonomously different choices in terms of spectroscopic techniques and system performance. ● **Transferable communication skills** The students will be able to: o acquire competence in communication in Italian and English in advanced fields of Physics o assess different spectroscopic methods for gas sensing o discuss a laboratory experiment and present results o access the state-of-the-art scientific literature of the reference topics with a deep knowledge and critical discussion on experimental methodologies and the related scientific results. ● **Lifelong learning skills** o acquire basic knowledge tools for continuous learning and knowledge updates o increase experience to work in a small group for a joint aim, o ability to present laboratory projects and report them in the form of a scientific paper, o integrate knowledge from English reference literature.
Syllabus	
Content knowledge	**Absorption and Emission of Light**. Discrete and Continuous Absorption and Emission Spectra. Transition Probabilities. Lifetimes. Spontaneous and Radiation-less 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 HITRAN Database. 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.
Texts and readings	W. Demtroder – Laser Spectroscopy – Basic Concepts and Instrumentation, Springer. J. Fraden – Handbook of Modern Sensors – Physics Designs and Applications, Springer.
Notes, additional materials	
Repository	Lecture notes at the website: http://polysense.poliba.it/index.php/physics-of-sensors-and-laboratory-of-spectroscopy/

Assessment	
Assessment methods	Oral exam with evaluation of the written report on laboratory activities

Assessment criteria	● *Knowledge and understanding:* o Knowledge of the properties of the emission and absorption spectra of gas species o Understanding the phenomena related to of radiation-matter interaction ● *Applied knowledge and understanding:* o Ability to apply the knowledge acquired on laser spectroscopy in a predictive and quantitative way it in the field of gas sensing ● *Making informed judgments and choices*: o Critical ability to select appropriate physical models to interpret phenomena involving infrared laser spectroscopy ● *Communication skills*: o Clarity and conciseness in the expository and presentation of a physical phenomenon related to spectroscopic techniques and analysis ● *Ability to learn:* o Ability to use fundamental concepts of classical and quantum mechanics to explain physical phenomena involving radiation-matter interaction in gas systems.
Final exam and grading criteria	The final grade is expressed on a 30-point scale. The minimum passing grade is 18/30, the maximum grade is 30/30 cum laude. The final exam will consist of the discussion of the technical report drawn up by the student in the form of a scientific article regarding the laboratory activities (50% of the final grade), and an oral part with discussion of two topics among them covered during lessons (50% of the final grade).
Further information	