UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Waves

2627-2-E3006Q013

Aims

This course introduces the fundamental concepts of wave phenomena, beginning with mechanical waves and progressing to electromagnetic waves. Emphasis is placed on developing the formal tools necessary to describe and analyze wave behavior across different physical systems. To promote a critical and comprehensive understanding of the material, lectures are supplemented by in-class experiments aimed at illustrating and deepening key concepts. In the final section of the course, attention shifts to modern physics. This leads to a transition to new concepts: the classical electromagnetic wave is reinterpreted through the notion of photon, and the classical material particle is associated with the concept of matter wave.

At the successful completion of the course, the student will have acquired the concepts necessary to describe wave phenomena, and will be able to approach their formal treatment (Knowledge and understanding), with particular focus on mechanical waves (sound) and electromagnetic waves, both in vacuum and in matter (Applying knowledge and understanding).
The student will be able to identify the most appropriate method for solving basic problems (Making judgements), and will be capable of using scientific language to communicate the acquired concepts in a rigorous and appropriate manner (Communication skills).

Contents

Waves: general concepts, physical qualnities, formalism, mechanical waves.
Electromagnetic waves, in vacuum and in the matter.
Modern physics.

Detailed program

1) General Concepts and Mechanical Waves
Recap of harmonic motion and the concepts of frequency, period, angular velocity, and frequency. Wave phenomena and the formalism used to describe them. Harmonic oscillator, forced and damped oscillator.
Wave function; wavelength, period, propagation speed. Principle of superposition. Harmonic waves: speed, ?, ?, ?, T, ?.
D'Alembert's equation and its derivation for harmonic waves. Longitudinal and transverse waves; polarization.
Interference of harmonic waves. Beats. Wave groups, phase and group velocity; wave packets. Standing waves. Diffraction.
Dynamics and wave equation for mechanical waves in a string. Energy, power, intensity.
Sound: general characteristics; the features of sound. Introduction to Fourier's theorem.
CLASSROOM EXPERIMENTS: free, damped, and forced oscillator; standing waves on a stretched string; wave scope (interference and diffraction)

2) Electromagnetic Waves
In Vacuum
Fundamental laws of electromagnetism: review and insights. Properties of E and B: Gauss's law; conduction and displacement current: Ampère-Maxwell law; electromagnetic induction.
Maxwell's equations in vacuum, in the absence of charges and currents. E and B as wave functions; electromagnetic waves and propagation. Transversality of electromagnetic waves and polarization; propagation speed. Examples of wave functions.
Polarization, interference, diffraction, and light scattering.
Power, energy, intensity. Poynting vector: definition and significance. Electromagnetic spectrum.
CLASSROOM EXPERIMENTS: diffraction

In Matter
Properties of E and B and Maxwell's equations in media. Wave propagation in media: Maxwell's equations. E and B as wave functions. Propagation speed and attenuation: refractive index and dielectric function.
Absorption and emission spectra of atoms, molecules, and solids; spectral lines, emission.
Interfaces: continuity of fields and laws of reflection and refraction. Fresnel coefficients; reflection (R) and transmission (T) at normal incidence (note on ?>0). Reading a transmission spectrum; Lambert-Beer's law. R and T of a thick film and a lens. Thin films; multilayers. Anti-reflection coatings. Dichroism and polarizing lenses; filters.
CLASSROOM EXPERIMENTS: spectrophotometer (absorption and fluorescence)

3) Modern Physics
from Wave to Particle
Blackbody spectrum, classical theory, and Planck's proposal; the quantum of energy.
Photoelectric effect. Apparatus and experimental observations; classical vs. quantum interpretation. Particle model of light; the photon.

from Particle to Wave
De Broglie's hypothesis. Brief notes on the Davisson-Germer and Thomson experiments.
The quantum particle, matter wavefunction ?. Harmonic wave and wave packet (why the packet is needed).
Born's probabilistic interpretation. Schrödinger equation.
Introduction to Bohr's model, molecular orbitals, and bands in solids. Radiation-matter interaction; transitions. Spectra of atoms, molecules, and solids.

Prerequisites

A solid understanding of the fundamental topics covered in first-year mathematics and physics courses is required to fully engage with the content of this course.

Teaching form

Lectures are delivered in Italian, with in-class experiments.
For the majority, there will be hours of Delivered Teaching (DE, traditional lectures), but there will also be hours of Interactive Teaching dedicated to in-class demonstration experiments.
Teaching will be conducted in person; to allow everyone to follow along, a recording made in the classroom will be made available to students for approximately 10 days after each lecture.

Textbook and teaching resource

For the first two parts of the program (mechanical and electromagnetic waves), the reference textbook can be:
S. Focardi, I. Massa, A. Uguzzoni, *Fisica generale - Onde e Ottica*, 2a ed. (Casa Editrice Ambrosiana, 2010)
Any university textbook dealing with classical physics can be used, such as that used for General Physics; in any case, asking the teacher is recommended.

For the third part of the program (modern physics), a good reference textbook can be:
D. Halliday, R. Resnick, J. Walker, *Fondamenti di Fisica - Fisica moderna* (CEA, 2025)

Semester

I semester

Assessment method

The final examination consists of two components: a written test and an oral examination.

Written Test:
The written test includes problem-solving exercises based on topics covered during the course, following formats and examples presented in class. It also includes one open-ended question. The use of books, notes, or any external materials is not permitted during the written test.

Midterm Exams:
Two or three midterm exams, each corresponding to a specific part of the course, are scheduled throughout the semester. Successfully passing all the midterms is considered equivalent to passing the written test.

Oral Examination:
The oral examination consists of a discussion of selected topics covered in class. It can be taken during the same exam session as the written test or in a subsequent session.

Office hours

By appointment (via e-mail), available on any weekday.

Sustainable Development Goals

QUALITY EDUCATION