UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Electromagnetism

2526-2-ESM01Q006

Aims

The course is part of the teachings of the Multidisciplinary Fundamentals area, concerning principles of chemistry and physics that, supported by mathematical tools, are part of the multidisciplinary basic training typical of materials science.
In the context of the expected learning outcomes, as regards **Knowledge and understanding**, the course intends to provide students with the fundamental tools, language and methodologies, for the description of electromagnetic and optical phenomena, preparatory to the understanding of the interaction of materials with electromagnetic fields and in particular with electromagnetic radiation.
The course also aims, through the involvement of students in the analysis of applicative examples of the introduced concepts and through connections to technological topics, to develop the **Ability to apply knowledge and understanding** to concrete problems. In particular, at the end of the course, students know how to approach the analysis of phenomena and material systems that involve interactions between electric charges according to a classical approach and are able to use the basic mathematical tools for their quantitative description.
The transversal presence of electromagnetic interactions in the physical-chemical characteristics of materials and in electrical, optical and structural functionalities, provides students with the opportunity to exercise the **Judgment skills** deriving from the need to understand, case by case, in the many examples and exercises proposed, the type of mechanisms and processes involved.
Both the ability to apply knowledge to real cases and the judgment skills necessary to orient oneself in the analysis of the extremely vast phenomenology of electromagnetism are applied during group works and interactions with the teacher aimed at developing in students those **Communication skills** that are the basis of the ability to constructively engage in an interlocutory manner with others, typical of the scientific field.
The Electromagnetism course, thanks to its highly formal structure but directly linked to the quantitative description of physical phenomena, aims to constitute an important opportunity for students to develop **Learning skills**, in particular the ability to acquire new concepts and use them to model reality, necessary to face the most advanced teachings, both in physical and chemical disciplines, and to exercise the ability to analyse problems and design solutions in the field of materials science.

Contents

The course starts from the description of the interactions between charged systems and introduces the concepts of electric field, flux of electric field, electrostatic energy and potential, giving the formal elements for both an integral and differential description. The course gives then the basis for the description of charging processes in conductors and polarization effects in dielectrics with the fundamental quantities describing charge transport in the electric conduction processes. The analysis of moving charges brings to the introduction of the concept of magnetic field and the effects of magnetic fields on moving charges, including charged systems with magnetic dipole moment. The course then analyses the electric and magnetic contributions arising from time dependent events, finally giving the general framework of Maxwell equations in their integral and differential forms. From these equations, the wave equations for the electric and magnetic components of the electromagnetic radiation are obtained, with also the basis for the general analysis of optical signals as overlapping monochromatic components. Finally, the course gives a short analysis of the formal tools for the description of both geometrical optics and electromagnetic wave propagation.

Detailed program

Electric charge. Conductors and insulators. Electrostatic induction. Description of electrostatic interactions in terms of the force between electric charges. Coulomb's law. Dielectric constant of vacuum. Principle of superposition. The concept of field. Force fields in physics. The electrostatic field generated by point charges. Description of continuous charge distributions and examples of electric fields. Motion of a charge in an electrostatic field: energy conservation.

Electric force and work. Work and potential energy. Conservative fields. Potential energy and electrostatic potential. Potential generated by point charges and continuous charge distributions. Relations between field and potential. Electric dipole. Dipole field and potential. Dipole in an external field.

Flow of a vector field. Flux of the electrostatic field. Gauss's law. Applications of Gauss's law. Insulated charged conductor. Electrostatic induction. Electrostatic screen. Capacity of a conductor. Capacitors. Calculation of the capacitance of a capacitor. Capacitors in series and in parallel. Energy and energy density of the electric field. Capacitors with dielectrics. Relative dielectric constant. Polarization of dielectrics.

Electric current. Current intensity and density. Resistivity and conductivity. Ohm's law in local form. Microscopic model of electrical conduction. Resistors in series and parallel. Joule effect. Electromotive force generators. Kirchhoff's laws.

Magnetic interaction and magnetic field. Moving charges in magnetic field. Laplace's second law. Electric currents in magnetic field. Mechanical moments on plane circuits. Magnetic dipole moment. Hall effect. Motion of charged particles in a magnetic field. Magnetic field generated by electric currents and moving charges. Laplace's First Law. Magnetic field generated by an infinite straight wire. Ampère's law. Applications of Ampère's law. Magnetic interaction between currents. Magnetic field generated by a circular coil and a solenoid. Local form of Ampère's law. Displacement current. Ampère-Maxwell equation. Magnetic materials. Magnetization. Dia, para and ferromagnetism.

Faraday's law; induced electromotive force and its origin. Induced electric fields. Applications of Faraday's law. Inductance. Energy and energy density of the magnetic field. Properties of induced electric fields and magnetic fields.

Maxwell's equations. Continuity equation of current. Maxwell's equations for time-varying fields in integral and differential form. Induced electric and magnetic fields. D'Alambert's equation for electromagnetic waves. Plane waves. Poynting vector. Intensity of plane waves. Polarization of waves: linear, circular and elliptical polarization. Notes on Fourier's analysis of waves and pulses.

Fundamentals of wave optics. Spherical waves. Speed ??of light in vacuum and in transparent media. Refraction and dispersion index. Huygens-Fresnel principle. Reflection and refraction. Spherical wave propagation, reflection and refraction and the role of material polarization.

Principles of geometric optics. Concave and convex spherical mirrors. Flat mirrors. Thin lenses. Interference between electromagnetic waves. Basic principles for the interpretation of interference phenomena.

Prerequisites

Basic knowledge of Mathematical analysis and Newtonian physics.

Teaching form

The course comprises in-presence classes, in Italian language, including sessions of exercises - aimed at training to transform knowledge in problem solving skills - and summary interactive lessons on the main three lecture blocks on i) electrostatic, ii) electric currents and magnetism, and iii) time dependent effects and optics, respectively. Interactive lessons include group works concerning the quantitative analysis of electromagnetic interactions on case studies related to materials and devices. In detail, the following activities are planned:

- 24 2-hour lessons carried out in frontal mode in the initial part, aimed at involving students in an interactive way in the subsequent part. All activities are in-person classes.
- 15 2-hour exercises carried out in frontal mode in the initial part, aimed at involving students in an interactive way in the subsequent part. All activities are in-person classes.
- 3 2-hour exercises carried out in interactive mode in interdependent groups. All activities are in-person classes.

Textbook and teaching resource

Reference textbook:

Elementi di fisica, Elettromagnetismo e onde – P. Mazzoldi, M. Nigro, C. Voci – EdiSES

Additional resources:

Exercises with resolution on the e-learning platform.

Semester

First semester

Assessment method

Students must first demonstrate to possess the formal tools for the description and quantification of situations in which charged systems and/or moving charges interact with each other and with either static or time dependent electromagnetic fields, and for the description of electromagnetic waves and simple optical systems.
The assessment method is an oral exam comprising a first part, asking for setting up the quantitative resolution of a problem, followed by an interview aimed at assessing the level of knowledge acquired on the entire program and verifying the awareness achieved of the physical meaning of electromagnetic quantities and relationships.

Office hours

10:00-12:00 Monday, Thursday, Friday
Students are invited to make an appointment by e-mail

Sustainable Development Goals

AFFORDABLE AND CLEAN ENERGY