FISICA GENERALE II

12 CFU - 1° and 2° Semester

Teaching Staff

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LEARNING OBJECTIVES

- **Module I**

  The course aims at providing basic knowlegde of classical electromagnetism topics included in the Course Content (see below) as well as the capability to apply the Scientific Method to the resolution of real and concrete problems.

  In particular, the course has the objectives to provide pupils with the following knowledge and abilities.

  Knowledge and understanding abilities

  Knowledge of the main phenomenological aspects related to electromagnetism, to the structure of matter, and to the interaction between electromagnetic radiation and matter, understanding of their physical implications and their mathematical description.

  Applying knowledge and understanding ability

  Ability to recognize the main physical laws that govern an electromagnetic phenomenon, and to apply them to solve problems and exercises at different levels of complexity and therefore of approximation, with the use of appropriate analytical and numerical techniques.

  Ability of making judgements

Evaluation of the order of magnitude of the variables that describe an electromagnetic phenomenon. Evaluation of the relevance of a physical law (axiom, principle of conservation, universal law, theorem, law in global/integral or local/differential form and its generality, properties of materials, etc.).

Communication skills

Capability to expose scientific concepts in a proper and inambiguous manner, at various levels.

Learning skills

Application to Physics of theoretical/mathematical techniques.

- **Electromagnetism**
  The course aims at providing the student with a somewhat detailed understanding of the electromagnetic field, its interaction with matter, as well as physical and geometrical optics.

  Knowledge and understanding:

  Knowledge of the basic phenomenology of electromagnetism and (very basic) structure of matter, as well as the interaction between (electromagnetic) radiation and matter. Understanding of their physical implications and their mathematical description.

  Applying knowledge and understanding:

  Ability to identify the main physical laws underlying an electromagnetic phenomenon, and to apply them to solve problems and exercises at a various level of complexity and approximation (both physical and numerical), using both analytical and numerical techniques, as appropriate.

  Making judgements:

  Estimating the order of magnitude of the main variables intervening in electromagnetism. Assessing the level of importance of a physical law (axiom, conservation law, universal law, theorem, global/integral vs local/differential version of a given law, and its degree of generality, properties of the materials, etc)

  Communication skills:

  Ability to describe scientific concepts with property of language, at various levels.

  Learning skills:

  Application of concepts and mathematical-theoretical techniques to physics.

COURSE STRUCTURE

- **Module I**
  Prerequisites

  According to the Curriculum Regulations, the course of Fisica Generale I, including passing the exam, is propaedeutic to that of Fisica Generale II. Furthermore, it is extremely useful that pupils have knowledge of the topics of the courses of Algebra and Analisi Matematica I and II, such as: algebra, geometry, trigonometry, analytic geometry, differential and integral calculus.

  Attendance to lectures

  Although it is not mandatory, attendance to classroom lectures is strongly recommended.

  Didactic activity

  Didactic activity consists of classroom lectures and exercises. Exercises can be both assignments of the teacher for the homework or driven by the teacher - or by tutors, if available - in the classroom.

  Didactic material

  A collection of exercises, many of which were assigned during the written exam sessions, is available on the web page of the course in the Studium portal (http://studium.unict.it), inside the section called Documenti.

  Learning verification

  The final exam consists of a written test followed by an oral exam. The written test, lasting 2 hours, consists of the resolution, justified and clearly commented, (A) of 2 problems related to Module 1 of the course and (B) of 2 problems related to Module 2 of the course. In the case of partial tests (see following tables), a maximum time of 1 hour is granted to each part (A or B). For the resolution of each problem is assigned a score between 0/30 and 7.5 / 30.
  Students who obtain a score of less than 15/30 in the written test (7.5 / 30, in the case of partial test) are advised against taking the oral test and are not allowed to take an oral test later than the next test written.
  The overall oral exam consists in the treatment of at least 3 distinct topics of the program, the first of which is chosen by the student. During the oral examination it may be necessary to demonstrate the theorems and important results included in the program with numerical evaluations of the order of magnitude of the physical quantities that are involved in a given phenomenon..

  Dates of the exams

  Check the following web page:

  - http://web.dmi.unict.it/corsi/l-35/esami

  Examples of asked questions and exercises

  Usually, the oral exam begins with the presentation of a topic chosen by the candidate. After that, the exam continues with questions like: "tell me about" ... one of the topics of the program. Some examples are the following:

- "Gauss law"
- "energy of the electrostatic field"
- "electrostatic field in dielectrics"
- "equation of continuiity of the electric charge; in static as well as dynamic conditions"
- "equations of magnetostatics"
- "charge and discharge of an RC circuit; the displacement current"
- "Faraday's law of electromagnetic induction"
- etc.

During the oral examination it may be necessary to demonstrate theorems and important results included in the program with numerical evaluations of the order of magnitude of the physical quantities involved in a given phenomenon.
A collection of exercises, many of which were assigned during the written exam sessions, is available on the course page on the Studium portal (http://studium.unict.it), in the Documents section.

Course structure

1. Introduction - Reference textbook: Feynman
2. Electrostatics - Reference textbook: Feynman
3. Electrostatic field in the matter - Reference textbook: Feynman
4. Magnetostatics - Reference textbook: Feynman
5. Electrical conduction - Reference textbooks: Feynman, Mazzoldi
6. Variable magnetic fields - Reference textbooks: Feynman, Mazzoldi

- **Electromagnetism**
  Lectures (taught classes).

DETAILED COURSE CONTENT

- **Module I**
  Introduction. Fundamental units of the International System. Features of a force. Forces and fields. Symmetry in physics and the vector concept. The electric forces. Electric and magnetic fields. Characteristics of vector fields. The laws of electromagnetism; anticipation of Maxwell's equations and their qualitative analysis. Differential calculus of vector fields (gradient, divergence, rotor, Laplacian). Integral calculus of vectors. Line integrals and circulation concept. Surface integrals and flow concept. Gauss and Stokes theorems. Fields with zero rotor and fields with zero divergence.

  Electrostatics. Coulomb's law and the superposition principle of the electric field. The electric potential and its relationship with the electric field. The flow of **E**. The law of Gauss and the divergence of **E**. Electric field of a charged sphere. Field lines and equipotential surfaces. Equilibrium in an electrostatic field. Equilibrium in the presence of conductors. Stability of atoms. The electric field of a linear charge. Electric field of a charged sheet and of two plates with opposite charges. Electric field of a charged sphere and a spherical shell. Correctness of dependence $1/r^2$. The fields of a conductor and the fields within a conductor's cavity. Equations for the electrostatic potential. The electric dipole. The potential of the dipole as a gradient. The dipolar and multipolar approximation of an arbitrary charge distribution. Electric forces in molecular biology: DNA structure and replication. Fields due to charged conductors. Image method. Electric fields in the vicinity of a conducting plane and a conducting sphere. The capacitor. Capacitors in series and in parallel. Dependence of the field from the curvature of a conductor: "tip effect". Methods for determining the electrostatic field. Two-dimensional fields and complex variable functions. Notable examples of electric fields: oscillations in plasmas and colloidal particles in an electrolyte. Electrostatic field of a grid. Electrostatic energy of the charges. Energy of a uniformly charged sphere. The energy of a capacitor and the forces on charged conductors. Energy in the electrostatic field. Energy of a point charge.

Electrostatic field in the matter. The dielectric constant. The polarization vector **P**. The polarization charges. The equations of electrostatics in the presence of dielectrics. Fields and forces in the presence of dielectrics. Molecular dipoles. Electronic polarization. Polar molecules and polarization by orientation.

Magnetostatics. The magnetic field and the Lorentz force on a moving charge. The cyclotron. The electric current and the conservation of the charge. The magnetic force on a current. The magnetic field of stationary currents, Ampère's law. The magnetic field of a rectilinear wire and a solenoid. Atomic currents. The Earth's magnetic field and the alternation of its sign. Northern lights. The vector potential and the choice of its boundary conditions (magnetostatic gauge). The vector potential due to known currents. Potential vector of a straight wire and a solenoid. Magnetic field of a small coil; magnetic dipole. Law of Biot and Savart. The forces on a current loop and the energy of a magnetic dipole. Mechanical and electrical energy. The energy of constant currents. Comparison between the magnetic field and the vector potential.

Electrical conduction. Ohm's law of electrical conduction. Power and Joule effect. Resistors in series and in parallel. Electromotive force (f.e.m.). Charge and discharge a capacitor through a resistor. Displacement current and its evaluation. Maxwell generalization of Ampère's law and effect of time-dependent electric fields. Kirchhoff's laws for electricity networks.

Variable magnetic fields. The physics of electromagnetic induction and the Faraday law. The alternating current generator. Scheme of operation of a power plant and entropic effects of the production of electricity through transformation from other forms of energy. Mutual inductance and self-induction. Inductance and magnetic energy. Complex numbers and harmonic motion. Forced oscillator with damping in mechanics and its analogy in electromagnetism. The RLC circuit in series. Electrical resonance and complex impedance. Series and parallel impedances. Resonances in nature.

- **Electromagnetism**
  Maxwell equations. Their derivation from the laws of electromagnetism. Scalar and vector potentials. Gauge invariance. Lorentz gauge. Coulomb gauge. Helmholtz theorem. Energy and momentum density of the electromagnetic field. Poyinting theorem and its vector. Maxwell tensor. Radiation pressure. Perfectly absorbing and perfectly reflecting surface.

  Waves. D'Alembert equation. Its general integral and initial values problem. Superposition principle for linear PDEs. Derivation of the wave equation for elastic waves in a solid rod and in a tight rope. Longitudinal and transverse waves. Harmonic plane waves. Wave frequency and wave vector. Wave period and wavelength. Dispersion relation. Phase. Fourier series. Linear, elliptic, circular polarization. Wave intensity. Energy propagation in wave phenomena. Three-dimensional waves. Wave front. Wave radius. Spherical waves. Laplacian in polar coordinates. Wave packet. Phase and group velocities. Doppler effect.

Electromagnetic waves. Hertz experiment. Plane waves. Polarization and helicity of an electromagnetic wave. Huygens-Fresnel principle and Kirchhoff theorem (hints). Reflection and refraction of an electromagnetic wave. Laws of Snell-Descartes. Reminder: refraction of the lines of the electromagnetic field. Fresnel formulas for waves polarized in a perpendicular and in a parallel direction to the incidence plane. Reflected and refracted intensity. Limit angle. Wave guides. Optical fibers. Brewster angle. Polaroids. Malus experiment. Dispersion and absorption. Mechanical analogy. Reminder: elliptic polarization.

Electromagnetic waves in matter. Drude-Lorentz model. Constitutive relations: phase difference between P and E. Physical meaning of the imaginary part of the dielectric function $\varepsilon(\omega)$. Qualitative behaviour of $\varepsilon(\omega)$ within the Drude-Lorentz model. Group velocity in a dispersive mean. Static and high-frequency limits: (dielectric) insulators and metals. Plasmas and their oscillations.

Interference. Superposition principle. Coherent sources. Optical path. Young double-slit experiment. Fresnel mirrors. Interference among N sources. Thin films. Thin wedge. Newton rings. Michelson interferometre.

Diffraction. Fresnel and Fraunhofer formulation. Fresnel diffraction by an obstacle. Fraunhofer diffraction by a rectangular slit. Analogy with Fourier transforms. Fraunhofer diffraction by a circular slit. Bessel functions (hint). Resolutive power of an optical system: Rayleigh criterion. Diffraction lattice. Dispersion. Emission and absorption spectra (hints). X-ray diffraction by crystals and quasicrystals (hints).

Geometrical optics. Eikonal equation and its physical meaning. Ray equation. Optical path. Reflection and refraction laws (again). Lagrange integral invariant. Fermat principle. Laws od Snell and Descartes. Main optical systems: plane and spherical mirrors; prism; spherical and plane dioptre; thin and thick lenses.

TEXTBOOK INFORMATION

- **Module I**
  1. R. P. Feynman, R. B. Leighton e M. Sands, *La Fisica di Feynman – Vol. 1 e 2* (Zanichelli, Bologna, 2007) - this book is also in English;

  2. P. Mazzoldi, M. Nigro e C. Voci, *Fisica - Volume II - II Edizione* (EdiSES, Napoli, 2008).

- **Electromagnetism**
  Textbooks recommended for Modulo 1:

  - Si veda la pagina: http://studium.unict.it/dokeos/2016/main/course_description.

  Textbooks recommended for Modulo 2:

  1. J. D. Jackson, Classical Electrodynamics (J. Wiley & Sons, Hoboken, NJ, 1998).

  2. P. Mazzoldi, M. Nigro, and C. Voci, Fisica. Vol. 2: Elettromagnetismo, Onde, 2 ed. (EdiSES, Napoli, 2007).

3. L. D. Landau and E. M. Lifsits, Teoria dei campi (Ed. Riuniti – Ed. Mir, Roma – Mosca, 1985); *also available in English.*

4. M. Born and E. Wolf, Principles of Optics (Pergamon, Oxford, 1980).

5. H. D. Young, R. A. Freedman, A. Lewis Ford, Principi di fisica. Vol. 2: Elettromagnetismo e ottica (Pearson, Milano, 2016); *also available in English.*