Classical Electrodynamics

Academic Year: (2022 / 2023) **Review date: 20-04-2022**

Department assigned to the subject: Physics Department

Coordinating teacher: MARTIN SOLIS, JOSE RAMON

Type: Compulsory ECTS Credits : 6.0

Year : 1 Semester : 1

REQUIREMENTS (SUBJECTS THAT ARE ASSUMED TO BE KNOWN)

Electromagnetism, general Physics and Mathematics (graduate level)

OBJECTIVES

The course provides the basics for an understanding of the electromagnetic field theory and the behaviour of charged particles in electromagnetic fields, mainly from a classical field theoretical point of view. The course includes electrostatics, magnetostatics, and their unification (Maxwell equations), electromagnetic waves and their propagation, as well as charged particle dynamics and radiation phenomena.

The course will provide the student with an appropiate training in electromagnetic field theory and charged particle dynamics especially suited for its application to plasma physics and nuclear fusion science

The following competences and skills should be acquired:

Basic competences:

* To acquire and understand a knowledge that provides a basis or opportunity to be original in the development and / or application of ideas, often in a research context
* To know how to apply the acquired knowledge and their ability to solve problems in new or unfamiliar environments within broader (or multidisciplinary) contexts related to their area of study
* Ability to integrate knowledge and face the complexity of formulating judgments based on information that, being incomplete or limited, includes reflections on the social and ethical responsibilities linked to the application of their knowledge and judgments
* Abitly to communicate their conclusions and the knowledge and ultimate reasons that support them to specialized and non-specialized audiences in a clear and unambiguous way
* To acquire learning skills that allow them to continue studying in in a way that will be largely self-directed or autonomous

General competences:

* Knowledge of the basic technical applications of physical science as traditionally studied in applied sciences
* To acquired sufficient training to open up to advanced studies in the specialization of the second year of the master's degree (focused on the field of nuclear fusion) and during the development of the master's final project
* To learn the basic philosophy of technical and scientific thought
* Ability to study and work on a practical problem independently
* Ability to develop theoretical models through which the research results can be described and understood
* Ability to communicate orally or in writing the procedure followed and the results obtained in the experiment together with its interpretation
* To develop a sense of responsability

DESCRIPTION OF CONTENTS: PROGRAMME

1. Electrostatics
   1.1 Electric field
      1.1.1 Electric charge
      1.1.2 Coulomb¿s law

        1.1.3 Electric field
        1.1.4 Continuous charge distributions
    1.2 Helmholtz¿s theorem
    1.3 Divergence of the electric field
        1.3.1 Divergence of the electric field. Gauss¿ law
        1.3.2 Gauss¿ law applications
    1.4 Curl of the electric field
        1.4.1 Curl of the electric field. Conservative property
        1.4.2 Electric potential
        1.4.3 The work done to move a charge
        1.4.4 Electrostatic energy
    1.5 Conductors
        1.5.1 Basic properties
        1.5.2 Systems of conductors. Capacitors
    1.6 Energy in electrostatics
        1.6.1 The energy of a point charge distribution
        1.6.2 The energy of a continuous charge distribution. Systems of conductors
        1.6.3 Energy as a function of the electric field
        1.6.4 Forces
    1.7 Special methods in electrostatics
        1.7.1 Poisson and Laplace¿s equations
        1.7.2 Properties of the Laplace¿s equation. Linearity and uniqueness theorem
        1.7.3 The method of images
        1.7.4 Separation of variables
2. Electric fields in matter
    2.1 Multipole expansion. The electric dipole
    2.2 Polarization
    2.3 The field of a polarized object. Bound charges
    2.4 Gauss¿ law in the presence of dielectrics. The electric displacement
    2.5 Linear dielectrics. Susceptibility, permittivity and dielectric constant
    2.6 Boundary conditions
    2.7 Energy in dielectric systems. Forces
3. Magnetostatics
    3.1 Electric current
        3.1.1 Current distributions. Current density
        3.1.2 Continuity equation
        3.1.3 Ohm¿s law. Conductivity and resistivity
        3.1.4 Joule¿s law
    3.2 Magnetic forces
        3.2.1 Magnetic field B
        3.2.2 Magnetic force on a moving charge. Cyclotron motion. Lorentz¿s force
        3.2.3 Magnetic force on a current carrying wire. Magnetic moment of a loop current
        3.2.4 Magnetic force on volume and surface current distributions. Current element
    3.3 The magnetic field of a steady current
        3.3.1 Force between currents (Ampère¿s law)
        3.3.2 The Biot-Savart law. Examples
        3.3.3 Magnetic field due to volume and surface current distributions
    3.4 The divergence of B. Magnetic flux
    3.5 The curl of B
        3.5.1 The curl of B. Ampère¿s law
        3.5.2 Applications of Ampère¿s law
    3.6 Magnetic vector potential
4. Magnetic fields in matter
    4.1 Multipole expansion of the vector potential. The magnetic dipole
    4.2 Diamagnetism, paramagnetism, ferromagnetism
    4.3 Magnetization
    4.4 The magnetic field of a magnetized object. Bound currents
    4.5 Ampère¿s law in magnetized materials. The magnetic field H
    4.6 Linear and nonlinear media:
        4.6.1 Magnetic susceptibility and permeability
        4.6.2 Ferromagnetism. Hysteresis
    4.7 Boundary conditions
    4.8 Magnetic circuits
    4.9 Magnetic scalar potential
5. Electromagnetic induction

5.1 Electromotive force
5.2 Faraday¿s law of induction. Lenz¿s law
5.3 Moving circuits. Motional electromotive force
5.4 Stationary media. Induced electric field
5.5 Mutual inductance and self-inductance
5.6 Magnetic energy
5.6.1 Magnetic energy for a system of current-carrying circuits
5.6.2 Magnetic energy for steady current distributions
5.6.3 Energy as a function of the magnetic field
5.6.4 Losses due to hysteresis
5.6.5 Magnetic forces
6. Electromagnetic properties of superconductors
6.1 Introduction. Superconductivity. Critical temperature and critical magnetic field. Meissner effect. Type I and type II superconductors
6.2 Two descriptions for the magnetic state of superconductors:
6.2.1 Perfect diamagnetic material
6.2.2 Material with free surface current
6.3 London¿s equations. London penetration depth
7. Maxwell¿s equations
7.1 Generalized Ampères¿s law. Displacement current
7.2 Maxwell¿s equations
7.3 Maxwell¿s equations in matter
7.4 Boundary conditions
7.5 Conservation laws
7.5.1 Charge conservation. Continuity equation
7.5.2 Energy conservation. Poynting¿s theorem
7.5.3 Momentum conservation. Maxwell¿s stress tensor
7.5.4 Angular momentum
8. Electromagnetic waves
8.1 Electromagnetic waves in vacuum
8.1.1 The wave equation for E and B
8.1.2 Monochromatic plane waves
8.1.3 Energy and momentum in plane electromagnetic waves
8.2 Electromagnetic waves in matter
8.2.1 Propagation in linear media
8.2.2 Reflection and transmission at normal incidence
8.2.3 Reflection and transmission at oblique incidence
8.3 Absorption and dispertion
8.3.1 Electromagnetic waves in conductors
8.3.2 Reflection at a conducting surface
8.3.3 The frequency dependence of permittivity
8.4 Guided waves
8.4.1 Wave guides. Transverse electric (TE) and magnetic (TM) modes. TE waves in a rectangular wave guide
8.4.2 Coaxial transmission line
8.4.3 Resonant cavities
9. Potentials and fields
9.1 Scalar and vector potentials
9.2 Lorentz gauge and Coulomb gauge
9.3 Wave equations for the potentials
9.4 Retarded potentials
9.5 Point charges
9.5.1 Liénard-Wiechert potentials
9.5.2 The fields of a moving point charge
10. Radiation
10.1 What is radiation ?
10.2 Electric dipole radiation
10.3 Magnetic dipole radiation
10.4 Radiation from an arbitrary source
10.5 Power radiated by a point charge

LEARNING ACTIVITIES AND METHODOLOGY

* Lectures where the theoretical concepts are explained

The lecturer will provide the following information (1 week in advance)

- Main topics to be discussed during the session

- Chapters/sections in each of the text books provided in the bibliography where the student can read about these topics

* Practical lectures which include:

- Solution and discussion by the students of proposed exercises

- Application of the concepts discussed in the theoretical clases to plasma physics and fusion problems

* Tutorials:

The dates and times for the tutorials will be fixed via Aula Global. It will be possible to fix other tutorial sessions by appointment with the lecturer

ASSESSMENT SYSTEM

Continuous evaluation (100% of the final mark):

- Solution and discussion by the students during the practical clases of exercises proposed along the course (25%).

- Results of written exams (75%). These exams will mainly consist of the solution of proposed exercises related to the material discussed in the theoretical and practical lectures

% end-of-term-examination:	0
% of continuous assessment (assigments, laboratory, practicals…):	100

BASIC BIBLIOGRAPHY

- D.J. Griffiths INTRODUCTION TO ELECTRODYNAMICS, Prentice-Hall International, Inc., 1999
- J.R. Reitz, F.J. Milford and R.W. Christy FOUNDATIONS OF ELECTROMAGNETIC, Addison Wesley, 1992
- R. Wangsness ELECTROMAGNETIC FIELDS, John Wiley & Sons, Inc., 1986

ADDITIONAL BIBLIOGRAPHY

- J.D. Jackson CLASSICAL ELECTRODYNAMICS, Wiley & Sons, 1999
- L. D. Landau, E.M. Lifshitz THE CLASSICAL THEORY OF FIELDS, Course of Theoretical Physics, Vol.2, Pergamon Press, Ltd., 1975
- W.K.H. Panofsky and M. Phillips CLASSICAL ELECTRICITY AND MAGNETISM, Addison-Wesley Publishing Company, Inc., 1962