1. OVERVIEW

Subject area	Electromagnetism I
Degree	Bachelor's Degree in Physics
School/Faculty	Architecture, Engineering and Design
Year	2
ECTS	6
Type	Core
Language(s)	Spanish
Delivery mode	On campus
Semester	1

2. INTRODUCTION

The connection between electricity and magnetism is a relatively recent discovery, and they used to be thought of as two unrelated phenomena. However, at the start of the 19th century, experiments by Ørsted and Faraday suggested that electricity and magnetism were, in fact, closely related. These findings allowed Maxwell to sum up the theory of electromagnetism in just four equations. **Electromagnetism is essential** for any physics or engineering student **as it forms not only a basis for other fields of study, such as optics, relativity or quantum electrodynamics, but also the very foundations of our civilisation.**

The subject area is divided into **two parts**: one in the first semester and one in the second semester of the second year of the Bachelor's Degree in Physics. The aim of the **first part, Electromagnetism I**, is to **consolidate the fundamental knowledge acquired about the theory of electromagnetism in the subject area Fundamentals of Physics II**. During the course, mathematical formalism will be used to formulate Maxwell's equations in their differential and integral forms. The course begins with the study of electrostatics, both in a vacuum and in matter (metal and dielectric materials). This is followed by the study of magnetostatics, also both in a vacuum and in matter (diamagnetic, paramagnetic and ferromagnetic materials). The course ends with the study of electromagnetic induction and the formulation of Maxwell's equations of electromagnetism in their classical form.

By the end of the subject area, **students will have gained a complete overview of electromagnetism and its main applications. They will have built a solid foundation for studying other branches of physics associated with the theory of electromagnetism.**

Previous completion and a solid grasp of the subject areas **Fundamentals of Physics II** and **Mathematical Analysis II** is **recommended**.

3. SKILLS AND LEARNING OUTCOMES

Basic skills and general skills (CB and CG, respectively, by their acronym in Spanish):

- **CB1**. Students have shown their knowledge and understanding of a study area originating from general secondary school education, and are usually at the level where, with the support of more advanced textbooks, they may also demonstrate awareness of the latest developments in their field of study.
- **CB4**. Students can communicate information, ideas, problems and solutions to both specialist and non-specialist audiences.
- **CG1**. To understand key concepts, methods and findings in the different branches of physics while gaining a historical perspective of their development.
- **CG5**. To understand diverse phenomena that, despite being physically different, share certain similarities, allowing known solutions to be applied to new problems.

Cross-curricular skills (CT, by the acronym in Spanish):

- **CT4**. Written communication/Oral communication: Ability to communicate and gather information, ideas, opinions and viewpoints in order to understand and be able to act upon them, whether they are through spoken word and gestures, or through written word and/or visual aids.
- **CT5**. Problem solving: Be able to critically evaluate information, separate complex situations into their constituent parts, recognise patterns, and consider alternatives, different approaches and perspectives in order to find optimal solutions and negotiate efficiently.

Specific skills (CE, by the acronym in Spanish):

- **CE02**. To describe and analyse physical systems, identifying fundamental concepts and principles to make the approximations needed to build a simplified model.
- **CE03**. To understand the inherent limitations of classical physics that led to the emergence of the general and special theories of relativity and quantum mechanics, resulting in solutions to new physics problems.
- **CE04**. To understand the laws and principles of physics, to identify their logical and mathematical structure, their experimental basis and the phenomena described through them.
- **CE05**. To understand and know how to use the mathematical and numerical methods used in physics and in handling experimental data.

Learning outcomes (RA, by the acronym in Spanish):

- **RA1**. To explain the creation of electromagnetic fields through charges and currents, and how electromagnetic fields affect charges.
- **RA2**. To formulate the mathematical laws that explain electromagnetic phenomena and deduce their meaning and implications.
- **RA3**. To explain and apply Maxwell's equations in their differential and integral forms.

The following table shows how the skills developed in the subject area match up with the intended learning outcomes:

Skills	Learning outcomes
CB1, CB4, CG1, CG5, CT4, CE02, CE04	**RA1.** To explain the creation of electromagnetic fields through charges and currents, and how electromagnetic fields affect charges.
CB1, CB4, CG1, CG5, CT4, CE02, CE03, CE04	**RA2.** To formulate the mathematical laws that explain electromagnetic phenomena and deduce their meaning and implications.
CB1, CB4, CG1, CG5, CT4, CT5, CE02, CE03, CE04, CE05	**RA3.** To explain and apply Maxwell's equations in their differential and integral forms.

4. CONTENTS

This subject is organised into six learning units:

Unit 1. Scalar and vector fields

Vector algebra. Differential calculus (gradient, divergence, rotational and the Laplacian). Integral calculus (line, surface and volume integrals). Divergence theorem and rotation theorem. Helmholtz's theorem. Coordinate systems (cylindrical and spherical). Dirac delta function.

Unit 2. Electrostatics in a vacuum and in matter.

Coulomb's law. Electric field, **E**. Gauss's law. Electric potential. Laplace's equation and Poisson's equation. Electrostatics in conductors. Multipole expansion of potential. Electric dipoles. Polarization vector **P**. Bound charges (surface and volume). Electric displacement field, **D**. Boundary conditions of **E**, **P** and **D**. Electrostatic field work and energy. Linear dielectrics.

Unit 3. Magnetostatics in a vacuum and in matter.

Lorentz force. Electric current. Current densities and the continuity equation. Biot–Savart law. Ampere's law. Magnetic induction vector, **B**. Magnetic vector potential, **A**. Diamagnetism, paramagnetism and ferromagnetism. Magnetization vector, **M**. Magnetization currents. Auxiliary field **H**. Magnetic susceptibility. Boundary conditions **B** and **H**.

Unit 4. Electromagnetic field equations (Maxwell's equations)

Faraday–Lenz law. Self-inductance and mutual inductance. Magnetic field energy. Displacement current. Maxwell's equations in a vacuum and in matter. Boundary conditions.

Unit 5. Direct current and alternating current electric circuits.

Resistivity. Conductivity. Ohm's law. RC, RL and RLC circuits. Transformers.

5. TEACHING/LEARNING METHODS

The types of teaching/learning methods are as follows:

- **Lectures**: Presentations by the professor with the necessary technological tools to maximise comprehension of the learning content.
- **Collaborative learning:** Students complete collaborative activities to find creative, comprehensive and constructive solutions to questions and problems that arise from the given case studies, using all relevant knowledge and material resources available.
- **Problem-based learning**: Students are given problems and asked to solve them, working individually or in groups.
- **Guided academic activities:** Individual and group work that is more independent, including information searches, written summaries and public defence of projects.

6. LEARNING ACTIVITIES

The types of learning activities, plus the amount of time spent on each activity, are as follows:

On campus:

Learning activity	Number of hours
Lectures	24
Asynchronous lectures	12
Oral presentations of projects and debates	7.5
Report writing	13.5
Assessment	6
Practical activities (problems, written work, projects, workshops and/or lab work)	22.5
Group tutorials	10
Independent working	54.5
TOTAL	**150**

7. ASSESSMENT

The assessment systems as well as their weight with regard to the total grade are listed:

On campus:

Assessment system	Weighting
Knowledge tests (assessment system 1 or SE1) Students will sit two exams in the ordinary exam period with theoretical/practical questions and/or problems: one midterm exam and one final exam. The weighting of the midterm exam is 15% and the weighting of the final exam is 35%. In the extraordinary exam period, there is only one exam, covering all previous exams, with a weighting of 50%.	50%
Submission of group and/or individual exercises (SE2) Students will complete individual and/or group exercises that will be discussed and resolved in the problem-solving sessions.	30%
Oral defence of problems (SE3) Students must solve a problem in class during a problem-solving session. *This grade will only be awarded if the student has attended over 50% of the classes, whether on campus or online during class hours, and if the student is present when the problem is solved.*	10%
Performance observation (SE4) This is a subjective grade that is based on attendance, attitude towards the subject area, collaboration with classmates and respect for others in the classroom.	10%

On the Virtual Campus, when you open the subject area, you'll find details of your assessable tasks, including the submission dates and assessment procedures for each task.

8. BIBLIOGRAPHY

The reference material for the subject area is as follows:

- Griffiths, D.J.: ***Introduction to Electrodynamics (4th edition)***. Prentice Hall International (1999)
- Wangsness, R. K.: ***Electromagnetic Fields (2nd edition)***. Limusa (1979)

The recommended bibliography is indicated below:

- Feynman, R.P., Leighton, R.B., y Sands, M.: ***Lecturas de Física, Vol. II. Electromagnetismo y Materia*** Addison-Wesley Iberoamericana (1987)
- López, E. y Núñez, F.: ***100 problemas de Electromagnetismo***. Alianza Editorial (1997)
- Fernandez, A.G.: ***Problemas de campos electromagnéticos***. McGraw-Hill (2005)
- Reitz, J. R.; Milford, F. J. y Christy, R. W.: ***Fundamentos de la Teoría Electromagnética (4ª edición)***. Addison Wesley (1996)
- Jackson, J.D., ***Classical Electrodynamics (3rd edition)***. Wiley (1998)