Course guide
295914 - FMF - Fundamentals of Functional Materials

Last modified: 28/01/2026

Unit in charge: Barcelona East School of Engineering
Teaching unit: 748 - FIS - Department of Physics.

Degree: BACHELOR'S DEGREE IN BIOMEDICAL ENGINEERING (Syllabus 2009). (Optional subject).
BACHELOR'S DEGREE IN CHEMICAL ENGINEERING (Syllabus 2009). (Optional subject).
BACHELOR'S DEGREE IN ELECTRICAL ENGINEERING (Syllabus 2009). (Optional subject).
BACHELOR'S DEGREE IN ENERGY ENGINEERING (Syllabus 2009). (Optional subject).
BACHELOR'S DEGREE IN INDUSTRIAL ELECTRONICS AND AUTOMATIC CONTROL ENGINEERING (Syllabus 2009). (Optional subject).
BACHELOR'S DEGREE IN MECHANICAL ENGINEERING (Syllabus 2009). (Optional subject).
BACHELOR'S DEGREE IN MATERIALS ENGINEERING (Syllabus 2010). (Optional subject).

Academic year: 2025 **ECTS Credits:** 6.0 **Languages:** English

LECTURER

Coordinating lecturer: ROBERTO MACOVEZ

Others: Macovez, Roberto
Gebbia, Jonathan Fernando

PRIOR SKILLS

It is recommended for students to have attended the courses of Physical Metallurgy, Electric and Magnetic Properties of Materials, and Mechanical Properties of Materials.

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Transversal:
02 SCS N3. SUSTAINABILITY AND SOCIAL COMMITMENT - Level 3. Taking social, economic and environmental factors into account in the application of solutions. Undertaking projects that tie in with human development and sustainability.
06 URI N3. EFFECTIVE USE OF INFORMATI0N RESOURCES - Level 3. Planning and using the information necessary for an academic assignment (a final thesis, for example) based on a critical appraisal of the information resources used.
07 AAT N2. SELF-DIRECTED LEARNING - Level 2: Completing set tasks based on the guidelines set by lecturers. Devoting the time needed to complete each task, including personal contributions and expanding on the recommended information sources.

TEACHING METHODOLOGY

Theory and case study lectures: the Lecturer introduces fundamental concepts and few proofs, complementing them with key examples and the discussion of some applications.

LEARNING OBJECTIVES OF THE SUBJECT

At the end of the course, the student should be able to:
- Describe the functional properties of materials, in particular those related with phase transitions and latent heat; electrical conduction in metals, semiconductors and superconductors; mechanical, dielectric and optical properties; ferromagnetic and ferroelectric properties
- Discuss the applications of magnetic, superconducting and ferroelectric materials, as well as those of glasses and polymer-based materials.
- Describe quantitatively the electric, electromagnetic and viscoelastic response of materials, and its physical origin.
- Address conceptual problems related to the challenges of current and future technologies in various engineering domains (e.g., energy) related to functional materials.

STUDY LOAD

Type	Hours	Percentage
Hours large group	60,0	40.00
Self study	90,0	60.00

Total learning time: 150 h

CONTENTS

Unit 1: Phase transitions and ferroic materials

Description:
Topic 1.1 Magnetic domains
Introduction to magnetism in solids. Classical (Langevin) paramagnetism. Ising model. Solution in 1D. Ising Model in 2D, Curie-Weiss, Bragg-William Method. Micromagnetic theory: exchange, magnetostatic and Zeeman energies. Magnetic domains, domain walls, hysteresis and frustration.

Topic 1.2 Structural phase transitions and microstructure
Thermodynamics of phase transitions. Ehrenfest classification and hysteresis. Landau theory of phase transitions. Ferroelastic phase transitions: elasticity, order parameters and elastic compatibility. Ferroelastic microstructure and self-accommodation. Thermomechanical effects.

Topic 1.3 Magnetoelastic coupling and magnetostructural transitions
Magnetoelastic coupling. Magnetostructural phase transitions. Coupled magnetic and structural order parameters. Functional properties derived from magnetostructural coupling.

Specific objectives:
At the end of block 1, students will be able to:
• understand and describe magnetic ordering and domain formation in solids.
• analyze structural phase transitions using thermodynamic and Landau-type approaches.
• identify and characterize ferroelastic behavior and the origin of ferroelastic microstructures.
• Identify and characterize magnetoelastic and magnetostructural coupling mechanisms.
• recognize functional properties arising from coupled magnetic and structural transitions.

Related activities:
Final exam.

Related competencies :
02 SCS N3. SUSTAINABILITY AND SOCIAL COMMITMENT - Level 3. Taking social, economic and environmental factors into account in the application of solutions. Undertaking projects that tie in with human development and sustainability.
06 URI N3. EFFECTIVE USE OF INFORMATI0N RESOURCES - Level 3. Planning and using the information necessary for an academic assignment (a final thesis, for example) based on a critical appraisal of the information resources used.
07 AAT N2. SELF-DIRECTED LEARNING - Level 2: Completing set tasks based on the guidelines set by lecturers. Devoting the time needed to complete each task, including personal contributions and expanding on the recommended information sources.

Full-or-part-time: 50h
Theory classes: 20h
Self study : 30h

Block 2. Crystalline conducting and insulating functional materials: fundamentals and applications

Description:
Topic 2.1 - Crystals: lattice vibrations and electronic structure; semiconductors; superconductivity
- Lattice vibrations: transverse and longitudinal; acoustic vs optical modes
- Electrons: Schrödinger equation, Bloch’s Theorem, crystal momentum, electronic bands
- Classification of materials as metals vs semiconductors or insulators
- Current density; mobility, Ohm’s law, DC conductivity
- Metals and semiconductors in magnetic fields: Hall effect
- Superconductors: zero resistance & perfect diamagnetism, superconducting gap; critical field & superconducting currents; London’s equation; magnetic flux quantum; applications.

Topic 2.2 - Insulating materials: polarization properties; piezo-, para-, & ferro-electricity
- Polarization and bound charge
- Polarizability and dielectric constant of linear dielectrics, mechanisms of polarization
- Microscopic description: Clausius-Mossotti formula
- Ferroelectric materials: spontaneous polarization; polarization catastrophe of paraelectric phase; Curie temperature; ferroelectric domains; applications.

Topic 2.3 - High-frequency electromagnetic properties of metals, semiconductors & insulators
- AC Drude model of metals and doped semiconductors; plasmons and reflectivity of metals
- Cyclotron resonance frequency
- Lorentz model of the optical properties of vdW and ionic insulators, refractive index
- Optoelectronic applications of semiconductor diodes: LED/laser diodes, solar cells
- Lyddane-Sachs-Teller relation; soft phonon modes and ferroelectric transition

Specific objectives:
At the end of Unit 2, the students will be able to:
- Describe charge transport in semiconductors, metals and superconductors, and the effect of an applied magnetic field
- Discuss the phenomenology and the applications of superconductors
- Describe ferroelectric materials: ferroelectric polarization, ferroelectric domains, P-E hysteresis loops
- Use the Drude and Lorentz models to describe the high-frequency electromagnetic response of metals, semiconductors and insulators
- Understand the structure and work principle of sola cell devices
- Apply theoretical knowledge to problem solving

Related activities:
Final exam.

Related competencies :
02 SCS N3. SUSTAINABILITY AND SOCIAL COMMITMENT - Level 3. Taking social, economic and environmental factors into account in the application of solutions. Undertaking projects that tie in with human development and sustainability.
06 URI N3. EFFECTIVE USE OF INFORMATI0N RESOURCES - Level 3. Planning and using the information necessary for an academic assignment (a final thesis, for example) based on a critical appraisal of the information resources used.
07 AAT N2. SELF-DIRECTED LEARNING - Level 2: Completing set tasks based on the guidelines set by lecturers. Devoting the time needed to complete each task, including personal contributions and expanding on the recommended information sources.

Full-or-part-time: 50h
Theory classes: 20h
Self study : 30h

Unit 3. Disordered & polymeric functional materials: fundamentals and applications

Description:
Topic 3.1 - Introduction to (dynamically) disordered materials
1.1 Molecular & macromolecular constituents and dynamics; glasses and mesophases
1.2 Entropy & the Boltzmann distribution, application to orientationally disordered crystals
1.3 Plastic crystals for energy applications
1.4 Electrical and mechanical properties of disordered materials: ion conductors and viscoelasticity

Topic 3.2 - Glasses
2.1 Crystallization vs glass transition and ageing
2.2 Adam-Gibbs theory and dynamic-thermodynamic correlation
2.3 Variety of amorphous solids and their mechanical, solid-state chemistry and optical applications
2.4 Single-component vs multi-component glasses, pharmaceutical relevance

Topic 3.3 - Polymeric materials and their applications
3.1 Amorphous & semicrystalline polymer materials; conformation of linear polymers: Miller theory & Kuhn ideal chains
3.2 Mechanical properties: normal (Rouse) & segmental relaxations; viscoelasticity of polymer melts
3.3 Rubbers and hydrogels: entropic elasticity, mechanical and energy applications
3.4 Liquid crystal polymers and fibres, block-copolymers, composite materials and amorphous polymer dispersions, and their applications

Specific objectives:
At the end of Unit 3, the students will be able to:
- describe the types of condensed phases that can be displayed by a single-component system based on the shape and size of its microscopic constituents, and ascertain which phases are observed at lower or higher temperature;
- describe the main experimental techniques available to identify phases and study molecular dynamics and phase transitions;
- discuss the degree of disorder inherent to a condensed phase, and its main characteristic microscopic dynamic processes; discuss the role of disorder and dynamics for rheological and mechanical properties.
- use random walk models, self-similarity, affine deformation and entropic elasticity theory to describe the properties of linear polymers and of polymer networks (elastomers);
- classify phase transitions, and describe the phenomenology of the glass transition in a number of systems ranging from atomic and molecular structural glasses to plastic crystals, and from liquid crystals to polymers
- describe the main technological applications of glasses and of synthetic polymers

Related activities:
Final exam

Related competencies :
02 SCS N3. SUSTAINABILITY AND SOCIAL COMMITMENT - Level 3. Taking social, economic and environmental factors into account in the application of solutions. Undertaking projects that tie in with human development and sustainability.
06 URI N3. EFFECTIVE USE OF INFORMATI0N RESOURCES - Level 3. Planning and using the information necessary for an academic assignment (a final thesis, for example) based on a critical appraisal of the information resources used.
07 AAT N2. SELF-DIRECTED LEARNING - Level 2: Completing set tasks based on the guidelines set by lecturers. Devoting the time needed to complete each task, including personal contributions and expanding on the recommended information sources.

Full-or-part-time: 50h
Theory classes: 20h
Self study : 30h

GRADING SYSTEM

The student's final mark will be the final exam, which will be a written exam on all the syllabus covered during class. Students will have available, on the Atenea platform, a list of problems that are similar to those that can appear in the final exam.

Reevaluation tasks will not be performed.

EXAMINATION RULES.

Students will take the final written exam individually. During the exam, they won't have access to the study material nor the internet network.

BIBLIOGRAPHY

Basic:
- Sears, Francis Weston; Salinger, Gerhard L. Termodinámica, teoría cinética y termodinámica estadística. 2ª ed. Barcelona [etc.]: Reverté, DL 1978. ISBN 9788429141610.
- White, Mary Anne. Physical properties of materials. 2nd ed. Boca Raton (Florida): CRC Press, cop. 2012. ISBN 9781439866511 (CART.).
- Kittel, Charles. Introduction to Solid State Physics. 8th. Wiley, 2005.
- Jones, Richard A. L. Soft condensed matter. Oxford [etc.]: Oxford University Press, 2002. ISBN 9780198505891.
- Strobl, Gert. The Physics of Polymers : concepts for understanding their structures and behavior [on line]. Berlin Heidelberg New York: Springer Verlag, 2007 [Consultation: 14/09/2022]. Available on: https://ebookcentral-proquest-com.recursos.biblioteca.upc.edu/lib/upcatalunya-ebooks/detail.action?pq-origsite=primo&docID=3062750. ISBN 9783540252788.

Complementary:
- Wadhawan, Vinod. Introduction to ferroic materials. CRC Press, 2000. ISBN 9789056992866.
- Planes, Antoni; Mañosa, Lluís; Saxena, Avadh. Magnetism and structure in functional materials : workshop of the Interplay of Magnetism and Structure in Functional Materials, held al the Benasque center for Science in the Pyrenees mountainsm, February, 9-13, 2004. Berlin: Springer, 2005. ISBN 9783540236726.
- Salje, Ekhard K. H. Phase transitions in ferroelastic and co-elastic crystals : an introduction for mineralogists, material scientists, and physicists. Cambridge [etc.]: Cambridge University Press, 1993. ISBN 0521384494.
- Doi, Masao. Soft matter physics. Oxford: Oxford University Press, 2013. ISBN 9780199652952.

RESOURCES

Other resources:
During the course, lecture notes will be available through the Atenea platform. Students will also have access to lists of problems associated with each unit fo the course. The final exam will contain problems that are similar to those of the lists.