COURSE DATA

Data Subject	
Code	34263
Name	Solid-state physics
Cycle	Grade
ECTS Credits	7.5
Academic year	2021 - 2022

Study (s)

Degree	Center	Acad. year	Period
1105 - Degree in Physics	Faculty of Physics	4	First term

Subject-matter

Degree	Subject-matter	Character
1105 - Degree in Physics	15 - Expansion of Physics	Obligatory

Coordination

Name	Department
PELLICER PORRES, JULIO	175 - Applied Physics and Electromagnetism
SANCHEZ ROYO, JUAN FRANCISCO	175 - Applied Physics and Electromagnetism

SUMMARY

The subject of Solid State Physics aims to provide an introduction to the physics of solids that familiarizes students with the crystalline and electronic structures of materials and the way in which both determine the basic properties of solids and their possible technological applications. The Solid State is a matter that connects the macroscopic world with the microscopic one and therefore fundamental in the development of a Physicist. In this subject, the fundamental properties of matter are studied, relating them to their microscopic origin.

The subject has 7.5 ECTS credits assigned, of which 6 are theoretical and 1.5 are laboratory practices.

In the subject of Quantum Physics, of the third year, some fundamental aspects of the Solid State are studied, such as Bloch's theorem, the existence of energy bands (Kronig-Penney model) and the dispersion relations, the periodic conditions of Born-von Karman, the effective mass or the hollow concept. The Drude model of driving in a metal is also studied. These concepts are assumed to be known by students, although some of them are reviewed in the context of its corresponding topic. In the subject, extensive use is made of the tools developed in the subjects of Mechanics, Electromagnetism, Thermodynamics and Statistical Physics. In parallel to the Physics of the Solid State, the students study

Quantum Mechanics. Many of the concepts developed in this subject are important in the subject of Solid State, in particular in the study of semiconductors, and later in magnetism and superconductivity. On the other hand, the Physics of the Solid State gathers the necessary foundations to study other subjects, as Semiconductor Physics.

The development of the subject begins by analyzing the long-range periodicity and the symmetries it gives rise to. The different crystalline systems are studied and examples of structures of fundamental and technological interest are explained. Subsequently, the phenomenon of X-ray diffraction in crystals is analyzed. It begins by introducing the reciprocal network and the Brillouin zones to later describe some methods of solving structures.

Next, the problem called network dynamics is addressed, obtaining the dispersion relationships and introducing the phonon concept. The Brillouin and Raman scattering techniques are easily formulated for the study of acoustic and optical phonons, respectively. The thermal properties of solids are intimately related to phonons. The density of phonon states is defined, which will serve as the basis for the determination of a series of thermal properties such as heat capacity, thermal expansion or the effects of anarmonicity.

The electronic structure of solids is essential to know the electronic and optical behavior. In the subject two models are approached, that of the quasi-free approach, valid for metals, and that of the strongly bound electrons approach, valid for insulators. The band structure is analyzed in the first Brillouin area. The critical points are introduced. Then we analyze some known band structures and their densitiy of states.

The study of carriers begins with the semiclassical description of electronic transport, discussing why some materials conduct electricity and others do not. The Drude model is reviewed, emphasizing its weaknesses and the need to introduce the Fermi statistics to describe the electron gas. Also, the contribution of electrons to thermal conduction is studied. Semiconductors are the basis of much of today's electronic technology. After recalling some concepts that have been seen in Quantum Physics, such as the concept of hollow and effective mass, the concentration of electrons in a semiconductor and the evolution of Fermi energy as a function of temperature is determined. Doped semiconductors are studied.

Much of the macroscopic properties of a solid are defined by its dielectric function. The theme begins by describing the dielectric function of a set of harmonic oscillators. Next, the different polarization mechanisms in the solids are exposed. The relationship of the dielectric function with the optical parameters is detailed. In particular, infrared absorption, polaritons, polarization by orientation and the dielectric function of metals are studied. The relations of Kramers-Kronig are described. Finally, a brief introduction to ferroelectric materials is made.

The exhibition of magnetism begins with the quantum theory of diamagnetism and paramagnetism. Ferromagnetism, along with other variants of magnetic order, is a cooperative phenomenon, whose description requires introducing the so-called exchange interaction. The middle field theory of both ferromagnetism and antiferromagnetism is discussed. It differentiates the different magnetic behaviors through magnetic susceptibility as a function of temperature.

Finally, a quite complete vision is given to the phenomenon of superconductivity, starting from some essential experiments and then making a phenomenological description of its properties from the point of view of Electrodynamics and Thermodynamics. The origin of superconductivity is explained in a simplified way. Next, the different types of superconductors are analyzed. Finally, the Josephson effect is described.

PREVIOUS KNOWLEDGE

Relationship to other subjects of the same degree

There are no specified enrollment restrictions with other subjects of the curriculum.

Other requirements

General Physics, Mechanics and Waves, Quantum Physics, Thermodynamics and Statistical Physics, Optics, Electromagnetism, Mathematical Methods.

OUTCOMES

1105 - Degree in Physics

- Knowledge and understanding of the fundamentals of physics in theoretical and experimental aspects, and the mathematical background needed for its formulation.
- To know how to apply the knowledge acquired to professional activity, to know how to solve problems and develop and defend arguments, relying on this knowledge.
- Problem solving: be able to evaluate clearly the orders of magnitude in situations which are physically different, but show analogies, thus allowing the use of known solutions in new problems .
- Theoretical understanding of physical phenomena: have a good understanding of the most important physical theories (logical and mathematical structure, experimental support, described physical phenomena).
- Modelling & Problem solving skills: be able to identify the essentials of a process / situation and to set up a working model of the same; be able to perform the required approximations so as to reduce a problem to an approachable one. Critical thinking to construct physical models.
- Physics general culture: Be familiar with the most important areas of physics and with those approaches which span many areas in physics, or connections of physics with other sciences.
- Basic & applied Research: acquire an understanding of the nature and ways of physics research and of how physics research is applicable to many fields other than physics, e.g. engineering; be able to design experimental and/or theoretical procedures for: (i) solving current problems in academic or industrial research; (ii) improving the existing results.
- Foreign Language skills: Have improved command of English (or other foreign languages of interest) through: use of the basic literature, written and oral communication (scientific and technical English), participation in courses, study abroad via exchange programmes, and recognition of credits at foreign universities or research centres.
- Literature Search: be able to search for and use physical and other technical literature, as well as any other sources of information relevant to research work and technical project development.

- Learning ability: be able to enter new fields through independent study, in physics and science and technology in general.
- Communication Skills (written and oral): Being able to communicate information, ideas, problems and solutions through argumentation and reasoning which are characteristic of the scientific activity, using basic concepts and tools of physics.
- Students must have acquired knowledge and understanding in a specific field of study, on the basis of general secondary education and at a level that includes mainly knowledge drawn from advanced textbooks, but also some cutting-edge knowledge in their field of study.
- Students must be able to apply their knowledge to their work or vocation in a professional manner and have acquired the competences required for the preparation and defence of arguments and for problem solving in their field of study.
- Students must have the ability to gather and interpret relevant data (usually in their field of study) to make judgements that take relevant social, scientific or ethical issues into consideration.
- Students must be able to communicate information, ideas, problems and solutions to both expert and lay audiences.
- Students must have developed the learning skills needed to undertake further study with a high degree of autonomy.

LEARNING OUTCOMES

- Knowledge of basic concepts of symmetry related crystal structure.
- Knowledge-ray diffraction.
- Understand the basic equations of elasticity.
- Understanding the origin of physical phenomena such as thermal, electrical or optical roperties.
- Understanding the origin of magnetism and superconductivity.
- Management of physical concepts and mathematical tools needed to address a topic of research in solid state physics.
- Develop the ability to identify problems and devise strategies for resolution.
- Develop the ability to plan and organize their own learning, based on the individual work from the literature and other information sources.
- To assess the relative importance of different causes involved in a physical phenomenon.
- Identify the essential elements of a complex situation, make the necessary approaches to construct simplified models that describe it so we can understand their behavior in other situations.
- Be able to perform an update of the existing information about a specific problem, sort and analyze it critically.
- Develop capacity to work together.

DESCRIPTION OF CONTENTS

1. Crystal structure

Crystalline and amorphous materials: short and long distance order. Crystal lattices. Bravais lattice and motive of a crystalline structure. Elements of symmetry. Crystal classes. Crystal structures of technological interest.

2. Diffraction in periodic structures

Scattering of light by electrons. General theory of diffraction. Diffraction by periodic lattices: reciprocal lattice. Condition of Laue and sphere of Ewald. Bragg's interpretation of Laue's condition. Brillouin zone. Structure factor. Resolution methods of crystalline structures.

3. Crystal dynamics

Series expansion of the crystalline potential: harmonic model. Equations of the lattice dynamics: dynamic matrix and polarization vectors. Linear chain with one atom and two atoms in the unit cell: acoustic and optical branches. Simple cases of real dispersion in a solid. Brillouin and Raman effects for the study of acoustic and optical modes. Concept of phonon.

4. Thermal properties of solids

Phonon dispersion relationships and density of states. Thermal excitation of phonons: thermal energy and heat capacity. Debye approximation for the harmonic solid. Specific heat. Anharmonic effects. Thermal expansion. Thermal conductivity.

5. Electronic structure: band theory

Schrödinger equation of the electron in a periodic potential: Bloch's theorem. Quantum theory of the chemical bond.
Quasi-free electron approximation: metals. Tight binding approximation: insulators and semiconductors. Dispersion of the bands in the first zone of Brillouin: metals and semiconductors. Density of states: critical points or Van Hove singularities.

6. Metals

Drude model and associated problems. Free electron gas in a quantum well with infinite potential barriers. Fermi energy, density of states and Fermi surface.
Statistics of Fermi-Dirac. Electronic contribution to specific heat in a metal. Model of Sommerfeld.

7. Semiconductors

Band structure of semiconductors near to the gap: effective masses and concept of hole. Fermi level and its temperature dependence. Electrons and holes concentrations in an intrinsic semiconductor. Impurities: donor and acceptor. Temperature dependence of the Fermi level and carrier concentration of in a doped conductor. Drude model for a semiconductor. Carrier scattering by phonons and impurities.

8. Dielectrics

Dielectric function of a solid: Kramers-Kronig relations. Dielectric function of a harmonic oscillator distribution. Dielectric function and optical parameters. Longitudinal and transverse modes: polaritonic dispersion relations.

9. Magnetism

Kinetic moment and magnetic moment. Bohr magneton. Diamagnetism and paramagnetism.
The exchange interaction. Spin hamiltonian for ferromagnetism. Behavior of a ferromagnetic material with temperature. Antiferromagnetism. Magnons.

10. Superconductivity

Phenomenology of superconductivity. London equations. Cooper pairs: Fermi gas instability and fundamental state in the BCS theory. Josephson effect. Magnetic flux quantization. Type I and II superconductors. New superconductor materials.

WORKLOAD

ACTIVITY	Hours	% To be attended
Theory classes	60,00	100
Laboratory practices	15,00	100
Preparation of evaluation activities	20,00	0
Preparing lectures	47,50	0
Preparation of practical classes and problem	45,00	0
TOTAL	187,50	

TEACHING METHODOLOGY

Theoretical lectures: The bases of the Solid State are established, introducing the fundamental aspects from which their electrical, optical and magnetic properties are derived.

Practical lectures: Exercises are carried out that complement the theoretical classes. An attempt is made to introduce real physical magnitudes that allow the student to know the order of magnitude of the different physical parameters involved in their properties.

Laboratory sessions: The laboratory work will be carried out in small groups. The students work in group in taking the data and discussingf the results, in a preliminary analysis.

EVALUATION

The evaluation system considers both the assimilation of the aspects explained in theory and problem classes and in the laboratory. The written exam (80%) will evaluate the understanding of the theoretical-conceptual aspects and the formalism of the subject, both through theoretical questions and through conceptual and numerical questions. It will also include problems that assess the ability to apply formalism and the critical capacity with respect to the results obtained. The laboratory note (20%) is based on a continuous evolution of the questionnaires delivered.

In addition to the continuous evaluation work related to the laboratory, there is the optional possibility of increasing the weight of the continuous evaluation by carrying out problems in the classroom. These problems will be provided by the teacher in advance. The percentage of continuous evaluation could be increased up to a maximum of 30%.

To pass the course it is necessary to have a minimum grade of 4 in both the theory and the laboratory sections.

REFERENCES

Basic

- Solid State Physics, N. W. Ashcroft y N. D. Mermin, Holt-Saunders Int. Edt., 1976.
- Solid-Stated Physics: An introduction to principles of Materials Science, H. Ibach y H. Lüth, Springer, 2003.
- The Oxford Solid State Basics, Steven H. Simon, Oxford University Press (2013).
- Física del estado sólido. Ejercicios resueltos. Jesús Maza, Jesús Mosqueira y José Antonio Veira. Universidad de Santiago de Compostela.

Additional

- Solid State Physics, G. Burns, Academic Press, 1990.
- Solid State Physics, H. E. Hall, John Wiley & Sons, 1982.
- Quantum Theory of Solids, C. Kittel, Wiley, 1987.

ADDENDUM COVID-19

This addendum will only be activated if the health situation requires so and with the prior agreement of the Governing Council

TEACHING METHODOLOGY:

In case that health situation requires blended teaching, the teaching model approved by the Academic Degree Committee on July 23, 2020 will be adopted.

— Compulsory subjects: 50% student attendance in the classroom, while the rest of students attend the class in streaming broadcast. Two groups will be set with alternate days attendance to the classroom in order to guarantee 50% of teaching hours attendance for all students. Laboratory sessions will have a 100% attendance.

— Optional subjects: 100% attendance in all activities.

If a total reduction in attendance is necessary, classes will be broadcast by synchronous videoconference at their regular schedule, along the period determined by the Health Authority.