Universidad Zaragoza

Academic Year/course: 2023/24

60033 - Physics of magnetic materials

Syllabus Information

Academic year: 2023/24
Subject: 60033 - Physics of magnetic materials
Faculty / School: 100 - Facultad de Ciencias
Degree: 538 - Master's in Physics and Physical Technologies
589 - Master's in Physics and Physical Technologies
ECTS: 5.0
Year: 1
Semester: Second semester
Subject type: Optional
Module:

1. General information

This course describes the main phenomena and experimental methods associated with the field of magnetism and magnetic materials. Emphasis is made on the quantum theory of magnetism and related properties of interest for technological applications. It is recommended for students who have a previous solid background in Quantum Physics, Statistical Physics and Solid State Physics. Other courses of the Master that are complementary to this are: “Materials Science”, “Statistical Physics of Critical Phenomena and Complex Systems”, “Nanoscience and Nanotechnology”, “Quantum Theory of Condensed Matter Physicsa” and “Low Temperature Physics and Quantum Technologies”.

Magnetism is a discipline that has been an important part of the History of Science itself. During the 20th century, it underwent four revolutionary changes: understanding of the Quantum origin, its extension to high frequencies (dynamics and resonance), the consumer market applications and very recently, the emergence of spin electronics. The subject describes the main phenomena, theoretical developments and experimental methods associated with modern magnetism. Emphasis is made on the quantum theory of magnetism and on the properties of magnetic materials and their applications.

These aims are in agreement with the following Sustainable Development Goals (SDG) form United Nations (https://www.un.org/sustainabledevelopment/): Goal 4 Quality education.

2. Learning results

We are witnessing the emergence of spin dependent phenomena and related applications based on the concepts, experimental techniques, and materials covered in this course. These phenomena are also at the base of promising technologies in various areas including: information technology (spintronics), biomedical applications (MRI, magnetic nanoparticles) and energy conversion and storage (spin-caloritronics) coexisting with the more established applications of consumer market. A thorough understanding of quantum magnetism and the physics of magnetic materials will provide the student with the theoretical and experimental knowledge to help them move beyond the purely academic into very active and current research fields in Condensed Matter Physics.

The student is able to calculate the magnetic susceptibility of the free electron gas (Pauli paramagnetism and Landau diamagnetism) and of a system of localized moments (Brillouin).

The student is able to obtain the Hamiltonian for an ion in a crystalline environment and determine the splitting by the crystal field.

The student is able to identify the most common exchange interactions (Heisenberg, RKKY, superexchange, Hubbard).

The student is able to derive various models of ferromagnetism and calculate the spectrum of spin waves. The student is able to calculate the typical size of a magnetic domain and the width of the magnetic domain wall.

The student is able to experimentally determine different magnetic properties by using macroscopic (eg VSM) or microscopic (eg Lorentz microscopy) techniques.

The student is able to apply all the concepts to rationalize and classify the different most common magnetic materials by their phenomenology and their technological applications.

3. Syllabus

1. INTRODUCTION

2. DIAMAGNETISM. PARAMAGNETISM

2.1. Magnetic moment in quantum mechanics

2.2. Orbital Diamagnetisml

2.3. Pauli Paramagnetism

2.4. Landau Diamagnetism

2.5. Paramagnetism: Brillouin theory

2.6. Van Vleck Paramagnetism

2.7. Adiabatic Demagnetization

3. IONS IN SOLIDS: CRYSTAL ELECTRIC FIELD

3.1. Crystal Field

3.2. Single-ion anisotropy: Stevens operators

3.3. Kramers Theorem. Jahn-Teller effect

3.4. Spin Hamiltonian

4. EXCHANGE INTERACTIONS

4.1. Exchange interaction: Heisenberg hamiltonian

4.2. Exchange in insulators: superexchange, double exchange

4.3. Exchange in metals: direct exchange, RKKY

4.4. Impurities: Kondo effect

4.5. Hubbard model

5. FERROMAGNETISM. OTHER MAGNETIC ORDERS

5.1. Mean-field theory: Curie-Weiss law

5.2. Ferromagnetism in metals: Stoner model

5.3. Collective excitations: spin waves. Magnons

5.4. Mean-field theory

5.5. Antiferromagnetic spin waves

5.6. Ferrimagnetism

5.7. Spin glasses

6. MAGNETIC ANISOTROPY

6.1. Shape anisotropy

6.2. Magnetocrystalline anisotropy

6.3. Exchange anisotropy

6.4. Magnetic domains

7. MAGNETIC MATERIALS AND APPLICATIONS

7.1. Applications of hard magnets

7.2. Applications of soft magnets

7.3. Magnetotransport properties in magnetic materials

7.4. Magnetic sensors

7.5. Spin electronics and magnetic recording

4. Academic activities

The methodology followed in this course is oriented towards achievement of the learning objectives. It favors the acquisition of theoretical and experimental expertise in the field of magnetism and magnetic materials. In order to get these results, we have programmed activities that improve the active and continuous implication of students within the different topics.

The course consists of two distinct training activities: lectures (4 ECTS); and laboratory sessions and elaboration of reports (1 ECTS). These activities will allow the student to acquire the desired knowledge on the topics of the course and experimental competence in modern magnetism.

5. Assessment system

A continuous evaluation will take into account the personal work of the students throughout the course. The students will receive a questionnaire of different sections of the course and a selected topic to be developed and presented in class. The evaluation (70% of the final mark) will reflect the quality of the solutions given to these questionnaires and the oral presentation.

The course will also comprise three practical sessions in the laboratory. After such sessions the student will produce a report on each including the objectives and obtained results. The evaluation of these reports will be 30% of the final mark.

The course has been primarily designed for students who are able to attend the lectures on site. However, there will also be an evaluation test for those students who are either unable to attend these lectures or who fail in their first evaluation. The test will consist on solving a questionnaire evaluating the expected results of the course. The questionnaire will consist of the following two parts: (i) one questions related to the main concepts discussed in the course. The student will be given three hours to solve this part. It will be evaluated from 0 to 10 and the result will amount to 70 % of the final mark; (ii) A practical exercise in which the student will be asked to describe the elements and configuration of an experimental set-up appropriate to measure a given material magnetic property. The student will then be asked to operate the set-up in the laboratory. Allocated time: three hours. It will be evaluated from 0 to 10 and the result will amount to 30 % of the final mark.