COURSE DATA

Data Subject	
Code	34274
Name	Nuclear and particle instrumentation
Cycle	Grade
ECTS Credits	4.5
Academic year	2022 - 2023

Study (s)

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

Subject-matter

Degree	Subject-matter	Character
1105 - Degree in Physics	16 - Complements of Physics	Optional

Coordination

Name	Department
CASTILLO GIMENEZ, M VICTORIA	180 - Atomic, Molecular and Nuclear Physics

SUMMARY

The Nuclear and Particle Instrumentation is an optional subject taught in the second quarter of the fourth year of the Degree in Physics. It consists of a total of 4.5 ECTS, of which 1.5 are theoretical and 3 are taught in the laboratory. This course is part of the matter Complements of Physics and allows the graduate to acquire the basic knowledge of the main techniques for detection and analysis in Nuclear and Particle Physics.

The course is aimed at students who wish to engage in Nuclear and Particle Physics through their experimental side. It should be noted also the importance of the subject in the formation of good professionals in fields such as radiation detection, nuclear techniques and dose measures for the many technological applications where the Nuclear and radiation impact, as for example: medical (hospital radiophysicists formation), nuclear power plants, etc.. Students interested in having a conceptual and practical first contact with radiation, methods of measurement and its own instrumentation, have the opportunity to do so on this subject and in particular in its laboratory.

The detection and measurement of any radiation (photons, neutrons, charged particles, heavy ions, etc.) requires a basic understanding of the fundamental processes that occur when radiation passes through matter. These processes are the base of all the particle detection systems and at the same time they determine what should be the ideal detector in each case, as well as its sensitivity and efficiency. In this subject we study in detail different techniques and detector types. Also are explained in the lectures, and handled in the laboratory, different electronic modules for the formation, transport and analysis of the electrical pulses generated in the detectors. An important part of the course is devoted to data acquisition, its analysis and the interpretation of the experimental results.

PREVIOUS KNOWLEDGE

Relationship to other subjects of the same degree

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

Other requirements

The minimum knowledge that students have previously acquired and are necessary for the development of the subject are:

- Statistical treatment of data, error propagation and numerical methods, physics-oriented ("Statistical and Numerical Methods" course and the laboratories of the first three years of the grade).
- Computer Techniques.
- Electromagnetism.
- Quantum Physics and Quantum Mechanics.
- Nuclear and Particle Physics, including its laboratory.
- Solid State.

COMPETENCES (RD 1393/2007) // LEARNING OUTCOMES (RD 822/2021)

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.
- Ability to collect and interpret relevant data in order to make judgements.
- 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 .
- 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 (RD 1393/2007) // NO CONTENT (RD 822/2021)

SKILLS

- Understand the processes, techniques, detectors and measuring instruments in the field of Nuclear Physics, Spectroscopy and Particle Physics.

- Learn how to raise and carry out an experiment.

- Apply the scientific method in the resolution of experimental works.

- Knowing how to interpret the measurements obtained in the laboratory and perform the necessary analysis to obtain the final results and the physical quantities to be obtained.

- Express physical quantities correctly and assess their errors. Distinguish between systematic, random and instrumental errors. Knowing who to apply error propagation and to determine the accuracy of the results.

- Adjust statistics and probability distributions to experimental data. Extract physical magnitudes from the parameters obtained in the fits. Apply criteria for the goodness of the data and the performed fits.

- Prepare a report on the process of measurements, data analysis and interpretation of the results.

- Use with ease the applications and equipment for the data treatment and analysis, as well as for the presentation of results and reports.

SOCIAL OR CROSS SKILLS

The characteristics of the Degree in Physics:

- Develop critical thinking skills and the application of the scientific method.

- Be able to identify problems, including the similarities with others which solution is known, and devise strategies for their solution.

- Develop the ability to plan and organize their own learning, based on individual work, from the literature and other sources of information.

- Evaluate the different causes of a phenomenon and its relative importance.

- Identify the essential elements of a complex situation, make the necessary approaches to construct simplified models that describe and to understand their behavior and 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 in addressing the complex problems which require collaboration with others.

- Strengthen resource acquisition speaking and writing to carry out a clear and coherent scientific argument.

DESCRIPTION OF CONTENTS

1. INTRODUCTION

Lesson 1. Introduction
Basic concepts: cross section, mean free path, reduced length. Energy loss of particles in atomic collisions: Bethe-Bloch formula. Range. Energy loss of electrons and positrons: critical energy and radiation length. The interaction of photons. The electromagnetic shower development. The interaction of neutrons.

2. FUNDAMENTAL DETECTORS

Lesson 2. General characteristics of detectors
Sensitivity. Detector response. Energy resolution. The response function: deconvolution of the spectra. Efficiency. Dead time.

Lesson 3. Ionization detectors
Basic principles. Diffusion and drift of electrons and ions. Avalanche Multiplication. Ionization chamber. Proportional counter. Multiwire proportional chamber (MWPC). Drift chamber. Time projection chamber (TPC). Examples.

Lesson 4. Scintillation detectors
Features. Organic and inorganic scintillators. Light response and linearity. Intrinsic radiation efficiency. Basic elements of a photomultiplier tube (PM). Operating parameters: Supply voltage and gain. Linearity. Dark current. External factors. Coupling scintillator-PM. Examples.

Lesson 5. Semiconductor detectors
Basic properties of semiconductors. Doped semiconductors. The pn junction: depletion depth. Surface barrier detectors.

3. NUCLEAR ELECTRONICS

Lesson 6. Electrical signals in Nuclear Physics
Terminology. Analog and digital signals. Fast and slow signals. The frequency domain. Bandwidth.

Lesson 7. Electronics for signal processing
The standard NIM. Transmission of signals by coaxial cables. Characteristic impedance of the coaxial cable. Reflection of the signal and impedance adjustment. Preamplifiers. Amplifiers. Pulse Filters: CR and RC circuits. Shaping networks in amplifiers: RC circuits and CR-CR-CR-CR. Nuclear Electronics Modules: pulse generators, linear gates, delay lines, discriminators, analog-digital converters (ADC), time-amplitude converter (TAC), coincidence units, gate and delay generators.

Lesson 8. Measurement Techniques in Nuclear Instrumentation
Logical gates. Pulse height selection and counting systems. Coincidence techniques. Adjusting delays. Accidental coincidences. Examples of "triggers". Methods of measuring time intervals.

4. LABORATORY SESSIONS

Block 1. Scintillation detectors and photomultipliers.

- Study of the Compton effect.
Verification of the Compton law. Compton constant. Measurement of the cross section s a function of the angle (Klein-Nishina formula). Measurement of the electron energy recoil.

- Gamma-gamma coincidence and angular correlations.
Study of the gamma radiation correlations: angular and temporal. Coincidence techniques: coincidence module, delayed coincidence (TAC), the technique of the linear gate. Detector size effects. Measurement of the lifetime of nuclear states.

- Study of the cosmic radiation and determination of the muon lifetime.
Angular dependence of the cosmic ray flux. Hard and soft component of the radiation. Temporary measurements: determination of the muon lifetime.

Block 2. Ionization detectors and semiconductors.

- X-ray spectroscopy using a proportional counter. Physical characteristics of the X-ray emission. Moseley's law. X-ray fluorescence. Interpretation of the spectra. Identification of the materials.

- Beta-Spectroscopy using a silicon detector.
Nuclear beta decay. Internal conversion electrons. The response function. Deconvolution spectra. Signal processing and background. Kurie Plots. Internal conversion coefficients. Mass of the nuclides.

- Alpha-Spectroscopy using a silicon detector.
Nuclear alpha decay. Alpha particle energy loss: copper, nickel and air. Stopping power. Range-energy curve. The Landau distribution. Convolution with the detector response function.

WORKLOAD

ACTIVITY	Hours	% To be attended
Laboratory practices	30,00	100
Theory classes	15,00	100
Attendance at events and external activities	1,50	0
Development of group work	20,00	0
Study and independent work	8,00	0
Readings supplementary material	5,00	0
Preparation of evaluation activities	20,00	0
Preparing lectures	5,00	0
Preparation of practical classes and problem	8,00	0
TOTAL	**112,50**	

TEACHING METHODOLOGY

The course has two parts with a distinct methodology: 1) Theory and problems and 2) Laboratory, where you learn to handle detection systems, data processing and computer techniques. The development of classes is as follows:

1. **Theory and practical issues**. The credits of theory and problems are structured in classes of one hour, a total of 15 classes at two classes per week at the beginning of the eighth semester. The working methodology can be classified into the following sections:
    1. **Issues of theory**. The lessons or themes will be explained by the professor on the model of lecture. Each issue contains the concepts and explanations necessary for the subsequent problem solving and to be applied in the laboratory. The use of new technologies (electronic presentations) is especially appropriate for this subject, given the high content of schemas, tables, graphs showing experimental results and/or comparisons with theoretical predictions, diagrams, pictures of experimental devices and practical applications, and all kind of visual materials that allows the students relate the content with their applications. These presentations can be used as teacher's notes, but by no means the individual student work should be restricted to them. The use of literature is essential to understand the contents and the objectives of the course. Students have access, prior to the start of each topic, the teacher slides through the Virtual Classroom (http://aulavirtual.uv.es/).
    2. **Resolution of problems and practical issues**. This part is twofold, primarily provides individual study and student participation in class. Students have a collection of problems to solve and explain (at least those most significant) to their peers. Students can pose interesting exercise to consider that are not part of the collection.
2. **Lab**. The labs are the best teaching tool to complement and illustrate the contents of the subject discussed in the theoretical and practical classes and also familiarize students with equipment and techniques as well as instruct them in the scientific method. Practices are held in 10 sessions of 3 hours, at two sessions per week, once they have completed the lectures, ie 9 to 13 weeks of the

semester. Students, in groups of two or three, held two full practices (one in each block), from initial assembly to obtain all the results and information that can be extracted from them, through the calibration and determination of the efficiencies of the instruments, the acquisition of data and analysis, adjustments to the distributions, thorough analysis of errors and results. This should be reflected in the report.
Students will have, in good time, a practical manual that will guide them to carry out the experiments. The teacher will monitor the understanding of the script and guide students on conceptual and technical aspects necessary to successfully complete installation, data acquisition and analysis. Each student must have a laboratory notebook in which all information will be reflected for the work done. Attendance at laboratory classes is mandatory and the submission of reports is a necessary condition for passing the subject.

EVALUATION

The evaluation of the knowledge acquired by the student will be based on:

1. **Written exam.** The exam is mandatory and will constitute the 20% of the qualification. The exam will consist of: test of 10 questions (in each question a correct option versus three false) and a set of short questions of a theoretical-practical nature. The value of the test and of each of the questions will be specified in the exam itself. The use of books or notes will not be allowed for the exam. A minimum qualification of 4/10 will be required to average with the other notes, otherwise the subject will not be approved.
2. **Theoretical-practical personal work.** It will constitute 20% of the final qualification. A series of questionnaires and problems, related to the contents of the subject, will be proposed through the Virtual Classroom. Students must submit resolutions as the theory progresses. No qualification note is stipulated in this section to average with the other notes.
3. **Laboratory practices**. It will constitute 60% of the final qualification. Attendance at laboratory sessions is mandatory. The practices will be preferably done in couples. The laboratory credits will be evaluated by monitoring the work developed in the laboratory itself and the delivery of the corresponding reports, in memory and/or poster format. The reports of the practices should include: brief introduction, theoretical basis, instrumental used, methodology, treatment of the data (tables, errors, graphs, adjustments, etc.), results, conclusions and bibliography. The reports will be delivered at least the day of the theory exam. A minimum qualification of 5/10 will be required to average with the other notes, otherwise the subject will not be approved.
4. The final qualification must be equal or greater than 5/10 to pass the subject.

REFERENCES

Basic

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  G.F. Knoll. Radiation Detection and Measurement. John Wiley and Sons, 1979. Segunda Edición 1989.
  N. Tsoulfanidis. Measurement and Detection of Radiation. Hemisphere Publishing Corporation. 1983.

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  Bibliografía del laboratorio:
  M.V. Castillo, E. Higón. Manual de Prácticas de Instrumentación Nuclear (incluye bibliografía específica de cada práctica)
  Manuales de operación de los distintos módulos y detectores.
  Photomultiplier Tube. Pinciple to Aplication. Editado por Hamamatsu, 1994.
  J.F. Ziegler. Helium. Stopping Powers and Ranges in All Elemental Matter. Vol 4 of The Sttoping and Ranges of Ions in Matter. Pergamon Press, 1977.

Additional

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  D.H. Perkins. Introduction to High Energy Physics. Addison-Wesley, 1987.
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  Ph.D. Bevington. Data Reduction and Error Analysis for the Physical Sciences. Mc Graw Hill Book Co. 1969, 1995.

- CERN (European Laboratory for Particle Physics), http://www.cern.ch/
  Fermilab (Fermi National Laboratory), http://www.d0.fnal.gov/
  SLAC (Stanford Linear Accelerator Center), http://www.slac.stanford.edu/
  LBNL particle adventure, http://ParticleAdventure.org/
  Links to particle physics sites, http://sg1.hep.fsu.edu/~wahl/Quarknet/index.htm
  Fermilab particle physics tour, http://www.fnal.gov/pub/tour.html
  Brookhaven Nuclear data base, http://www.nndc.bnl.gov/
  PDG, Particle Data Group, http://pdg.lbl.gov/
  Lund/LBNL Nuclear Data Search, http://nucleardata.nuclear.lu.se/nucleardata/toi/
  Lund/LBNL Table of Isotopes, http://ie.lbl.gov/toi.htm