

## Hadrons and Nuclei from a Theoretical Perspective (C003793)

**Course size** *(nominal values; actual values may depend on programme)*

**Credits 6.0** **Study time 180 h**

**Course offerings and teaching methods in academic year 2023-2024**

null

**Lecturers in academic year 2023-2024**

Ryckebusch, Jan WE05 lecturer-in-charge

**Offered in the following programmes in 2023-2024**

null

**crdts offering**

**Teaching languages**

English

**Keywords**

Nuclear physics, hadron physics, electroweak interactions with nuclei and nucleons

**Position of the course**

This course is theoretically oriented, and deals with the structure of atomic nuclei and the substructure of its constituent nucleons. After introducing nucleon-nucleon potentials and the atomic nucleus as a many-body system, the focus is on the electroweak interaction as a tool to investigate the structure of nucleons and nuclei.

**Contents**

1. Introduction: Overview of energy and length scales in subatomic physics./ Nucleons as point particles. Different components of the nuclear force./ Hadronic degrees of freedom: baryons and mesons./ Quark-gluon structure of baryons and mesons.
2. Mathematical and computational tools: Angular momentum algebra. Spherical tensor operators and Wigner-Eckart theorem. Permutation symmetry./ Second quantization. mean-field approximation. Overview of "beyond mean-field" techniques./ Relativistic mean field.
3. Models for the nucleus: Realistic nucleon-nucleon interactions. Short-range repulsion. Nuclear matter./ The deuteron and "few-nucleon" systems./ The shell model for complex nuclei./ Collective motion./ Pairing and superfluidity in nuclei.
4. Electroweak interactions with nuclei: Current-current theories./ Electroweak nucleon currents./ Electroweak quark currents./ Multipole analysis and long-wavelength approximation./ Neutrino interactions with nuclei./ Final-state interactions.
5. Electroweak interactions with nucleons: Quark models./ Nucleon spectrum./ Electromagnetic and weak nucleon formfactors./ Pion formfactors./ Transition formfactors and helicity amplitudes./ Deep inelastic scattering./ Duality.

**Initial competences**

At least one course in quantum mechanics and subatomic physics.

**Final competences**

- 1 Able to determine the relevant degrees-of-freedom at the various subatomic scales.
- 2 Skilled in the use of 3j-, 6j- and 9j-symbols.
- 3 Able to link models for nucleon-nucleon interactions to scattering experiments and the structure of the deuteron.

- 4 To grasp the limitations and the successes of the nuclear shell model.
- 5 Able to understand the microscopic foundations of collective motion in nuclei.
- 6 Familiarity with the theoretical framework for electroweak interactions with nucleons and nuclei.
- 7 Fully understand why the electromagnetic probe is such a powerful tool to learn about the structure of nuclei and nucleons.
- 8 Skilled in the use of the multipole expansion of current-current interaction hamiltonians.
- 9 Explain the link between hadron and quark models.

#### **Conditions for credit contract**

Access to this course unit via a credit contract is determined after successful competences assessment

#### **Conditions for exam contract**

This course unit cannot be taken via an exam contract

#### **Teaching methods**

Group work, Seminar, Lecture, Independent work

#### **Extra information on the teaching methods**

The students are expected to study a scientific paper that is related to one of the topics of the course. The content of the scientific paper is explained to all fellow students.

#### **Learning materials and price**

Reading material is available through the electronic learning system.

#### **References**

- "The Nuclear Shell Model", K.L.G. Heyde.
- "The Structure of the Nucleon", A. Thomas and W. Weise
- "Introduction to Quarks and Partons", F. Close.
- "Theoretical Nuclear and Subnuclear Physics", J.D. Walecka
- "Subatomic Physics", Hans Frauenfelder and Ernest M. Henley

#### **Course content-related study coaching**

The lecturers can be consulted for additional explanations.

#### **Assessment moments**

end-of-term and continuous assessment

#### **Examination methods in case of periodic assessment during the first examination period**

Oral assessment

#### **Examination methods in case of periodic assessment during the second examination period**

Oral assessment

#### **Examination methods in case of permanent assessment**

Assignment

#### **Possibilities of retake in case of permanent assessment**

examination during the second examination period is possible

#### **Extra information on the examination methods**

Format of the oral exam:

1 the student receives questions and can work on those for half an hour ; she/he can make use of the course material

2 for half an hour the student is subjected to questions from the examiner

#### **Calculation of the examination mark**

- 40% of the total mark for the presentation of a scientific paper
- 60% of the total mark for the oral exam