Quantum mechanics II

Lecturers
Jean-Marc SPARENBERG (Coordinator) and Nicolas CERF

Course mnemonic
PHYS-H401

ECTS credits
5 credits

Language(s) of instruction
English

Course period
First term

Campus
Solbosch

Course content

Elements of scattering theory: elastic scattering, cross sections, scattering stationary states and amplitude, Born expansion and approximations (scattering integral equation, free-particle Green function), phase-shift method (partial waves, resonances, Levinson theorem).

Symmetries and invariances: discrete and continuous groups, generators, reducible and irreducible representations, Noether theorem, parity (intrinsic particle parity, weak-interaction parity violation), translations (generator, center-of-mass-movement separation) and rotations (generator, Euler angles, big and small Wigner rotation matrices, irreducible tensor operators, Wigner-Eckart theorem and corollaries, 6j, 9j and Racah coefficients).

Relativistic wave equations: elements of special relativity (Minkowski space time and 4-vectors, Lorentz and Poincaré groups, generators, electromagnetism, charged-particle hamiltonian), Klein-Gordon equation (gauge invariance, non-relativistic limit, antimatter, Dirac sea), Dirac equation (Dirac matrices and spinors, covariant and hamiltonian formulations, symmetries and invariances, non relativistic limit, big and small components, Zitterbewegung, Klein paradox).

Density operator: pure state, statistical mixture, quantum Liouvile equation, Wigner distribution, physical examples (Stern-Gerlach experiment, canonical ensemble).

Identical-particle systems: indistinguishability, exchange operators, symmetric group, Pauli principle, Fermi gas, Bose-Einstein condensates.

Second quantization: Fock space, creation/annihilation/number operators, N-fermion/boson state.

Approximate methods for N-body problem: mean field (Hartree-Fock), density functional (Thomas-Fermi).

Objectives (and/or specific learning outcomes)

In the study of a generic microscopic system (nucleus, atom, molecule, solid...), to identify the dominant physical effects (particles constituting the system, relevant interactions...) and to propose an adequate model for these. In particular, to identify the relevant orders of magnitude and the physical principles leading to efficient simplifications in the build up of such a model (relativistic treatment or not, geometrical symmetry identification, particle-identity exploitation...). In case the so-established model can be solved analytically or with limited numerical capacities, to calculate the physical properties of the studied system (spectrum, transition probabilities, cross sections...) and to compare them with experimental measurements.

Teaching method and learning activities

Lectures based on transparencies and/or blackboard (36h).

Exercise sessions on paper with occasional use of a calculator or a computer, to be prepared and completed at home (12 times 2h).

Contribution to the teaching profile

To complete quantum-physics knowledge necessary to an in-depth study of fundamental-physics and applied-physics disciplines based on this formalism (nuclear, atomic, molecular and solid-state physics, quantum optics and quantum information...).

To address more advanced quantum-physics notions in order to be able to consider a master thesis oriented towards theoretical fundamental physics (particle and fundamental-interaction physics, cosmology, quantum field theory, general relativity...).

References, bibliography and recommended reading

- C. Cohen-Tannoudji, B. Diu et F. Laloë, Quantum Mechanics, Volumes 1, 2, 3 (Wiley, 2019)
- J.-L. Basdevant et J. Dalibard, Quantum Mechanics (Springer, 2005)
- F. Schwabl, Advanced Quantum Mechanics (Springer, 2008)
- W. Greiner, Relativistic quantum mechanics. Wave equations (Springer, 2000)
- E. Lipparini, Modern Many-Particle Physics (World Scientific 2008)
- R.G. Parr and W. Yang, Density-Functional Theory of Atoms and Molecules (Oxford University, 1989)

Course notes

Syllabus, Université virtuelle and Podcast

Other information

Place(s) of teaching

Solbosch

Contact(s)

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Evaluation method(s)

Oral examination and written examination

Oral examination

Open question with short answer and Open question with long development

Examination with preparation

Evaluation method(s) (additional information)

First session (January)

- Oral examination on the part of Prof. Cerf
- Written examination on the part of Prof. Sparenberg
- Participation in the exercise sessions: preparation, attendance, involvement, closure

Second session

- Oral examination on the part of Prof. Cerf
- Written examination on the part of Prof. Sparenberg
- Participation in the exercise sessions: preparation, attendance, involvement, closure

Determination of the mark (including the weighting of partial marks)

Overall score (on 20 points):

- 2/3 on the part of Prof. Sparenberg (collisions, symmetries, relativistic wave equations)
- 1/3 on the part of Prof. Cerf (density operator, N-body problem, second quantization and approximate methods)

Participation in the exercises: between 0 and 1.5 points added to the overall score

Main language(s) of evaluation

English

Programmes

Programmes proposing this course at the Brussels School of Engineering

MA-IRPH | Master of science in Physical Engineering | finalité Professional/unit 1