UCLouvain

lphys1344 — Subatomic, atomic and molecular physics

2023

6.00 credits	45.0 h + 45.0 h	Q2

Teacher(s)	Delaere Christophe ;Génévriez Matthieu ;Lauzin Clément ;
Language :	French
Place of the course	Louvain-la-Neuve
Prerequisites	It is recommended that students master the notions of quantum physics as developed in the course LPHYS1241. Having followed LPHYS1342 and having followed and passed LPHYS1231 are assets.
Main themes	This teaching unit consists of an introduction to subatomic, atomic and molecular physics. It discusses the experimental foundations of these three disciplines and introduces the main models associated with them. The relationship between experiment (and associated experimental methods) and the theoretical understanding of observed phenomena is emphasized. Different concepts are discussed, such as the life time and the interaction cross section, to account for the phenomena that take place within these bound systems (nucleus, atom or molecule). The description of these interactions by means of potentials (sometimes effective) of interaction or average potentials is introduced as a common denominator for all three sections of this teaching unit. In particular : • In subatomic physics, discoveries at the origin of a consistent description of the processes of strong and weak nuclear interactions are presented (discovery of the electron, nucleus and neutron, cosmic rays, muons, pions). The concepts of binding energy are then described together with a brief introduction to the liquid drop model, the layered model, and the Yukawa potential. The elementary particles that constitute these systems are then introduced very succinctly (without necessarily starting a mathematical description of the fundamental interactions between these elementary particles). • In atomic physics, after a brief review of the quantum description of the hydrogen atom, the Hartree-Fock model, the configuration interaction and the fine and hyperfine coupling are introduced more precisely. We introduce Einstein coefficients and multipolar radiative transitions. This description is extended to iso-electronic series and negative ions. • In molecular physics, we introduce the Born-Oppenheimer approximation and we give an introduction to the description of the different degrees of freedom, rotation and vibration, and their mutual interactions.
Learning outcomes	**At the end of this learning unit, the student is able to :** **a. Contribution of the teaching unit to the learning outcomes of the programme** AA1 : 1.1, 1.3,1.4, 1.6,1.7, 1.8 AA2 : 2.2, 2.3, 2.4 AA3 : 3.2, 3.4, 3.5, 3.6 AA4: 4.1 AA5: 5.1 AA6: 6.3 **b. Specific learning outcomes of the teaching unit** At the end of this teaching unit, the student will be able to : **1.** explain natural phenomena at subatomic scales in a qualitative way; **2.** appreciate the intellectual contribution of the experimental discoveries underlying the theories involved; **3.** communicate and appreciate the fundamental theoretical hypotheses of the nuclear models by means of a specific diagrammatical language (probability amplitudes); 1 **4.** establish the electronic structure of an atom, especially spectral terms and electronic configurations; **5.** describe the first nuclear-related states by applying the basic principles of quantum physics; **6.** describe the classical nucleon-nucleon potential in the context of quantum physics and establish the correspondence between the amplitude (in space-time) of a process and its description in the centre-of-mass frame of reference; **7.** describe and apply the basic principles of atomic spectroscopy, including selection rules; **8.** describe the Hartree-Fock approach and the configuration interaction, and apply them to the numerical calculation of binding energies and dipolar matrix elements; **9.** properly manipulate atomic databases to derive transition frequencies, lifetimes, and branching ratios. **10.** describe the fundamentals of molecular physics, in particular the quantum description of molecular systems using molecular Hamiltonians and the corresponding (time dependent and time independent) Schrödinger equations; **11.** interpret the various representations of these equations and discuss their approximate solutions, in particular the adiabatic and diabatic representations, and the Born-Oppenheimer separation; **12.** interpret some simple models of molecular dynamics and spectral analysis;

13. describe the electronic structure, vibrations and rotations of diatomic molecules;

14. describe and apply the basic principles of spin, vibration and electron spectroscopy of diatomic molecules, including the basics of selection rules;

15. describe and apply the basic principles of the experimental approach in nuclear, atomic and molecular physics.

Evaluation methods

The assessment of learning will be done by written exam. The learning outcomes of more advanced topics will eventually be subject to an oral evaluation.

The written exam will include :

- open and closed questions with short or long developments

- problem-solving with quantified result.

Teaching methods

The learning activities consist of lectures, exercises, practical work, software manipulations and database consultations.

The pedagogical material of the lectures are the blackboard and the slide show. The lectures are intended to introduce the fundamental concepts, to motivate them by showing examples and establishing results, to show their reciprocal links and their relations with the different parts associated with this teaching unit, and to establish links with the rest of the teaching units of the Bachelor in Physical Sciences.

The practical work sessions aim to learn to use the ideas and formalism developed in subatomic, atomic and molecular physics in order to explain the results of experiments carried out in specific laboratory session or described in the framework of the lectures. These sessions will also allow students to choose and use calculation methods for their analysis, and to interpret the results obtained.

The laboratories carried out during specific practical session or the descriptions of past experiences, aim to give an introduction to experimental methods in these three disciplines and to validate the theoretical concepts seen during the course or the establishment of theoretical concepts following the observation made in the laboratory.

Content

I. Basic concepts (hourly volume of 7h).

1. Brief history of nuclear and particle physics
2. Relativity and antiparticles
3. Space-time symmetries and conservation laws
4. Interactions and Feynman diagrams
5. Particle exchange: forces and potentials
6. Observable quantities: cross-sections and decay rates

II. Atomic physics. (hourly volume of 12h).

1. Explanation of the structure of atoms and ions based on a brief review of the results of quantum physics and spectroscopy.
2. Hydrogen-like systems, quantum defect, Rydberg states.
3. Multi-electron systems: Hartree-Fock method.
4. Central field and corrections, coupling schemes, isoelectronic series.
5. Radiative transitions, dipole approximation, multipolar transitions, selection rules, radiative cascades.
6. Stark effect and atomic polarizability, negative ions.

III. Molecular physics (hourly volume of 12h).

1. The Born-Oppenheimer approximation.
2. Separation of coordinates.
3. Electronic states: molecular orbitals and atomic orbitals.
4. Vibrational states and rotational states.
5. Symmetries of diatomic molecules.
6. Correlation diagrams.
7. Radiative transitions, selection rules.

IV Subatomic physics phenomenology (hourly volume of 14h).

1. Mass spectroscopy
2. Nuclear shapes and sizes
3. Semi-empirical mass formula: the liquid drop model
4. Nuclear instability
5. Decay chains
6. # decay phenomenology
7. Fission
8. # decays
9. Nuclear reactions
10. Leptons
11. Quarks
12. Hadrons

Inline resources

Various resources (slides and related documents) are put online via the MoodleUCL platform.

Bibliography	B. H. Bransden, C. J. Joachain (1990), "Physics of atoms and molecules", John Wiley and sons, ISBN-13: 978-0582356924. K. S. Krane, "Introductory Nuclear Physics", 3rd edition, ISBN: 978-0-471-80553-3. Brian R. Martin, Graham Shaw, "Nuclear and Particle Physics: An Introduction", 3rd Edition, ISBN: 978-1-119-34461-2. C. Foot (2005), 'Atomic Physics', Oxford University Press, ISBN: 9780198506966
Other infos	**Following the sanitary conditions, the modalities of the teaching AND the examination could be reassessed according to the situation and the rules in force.**
Faculty or entity in charge	PHYS

Programmes containing this learning unit (UE)				
Program title	Acronym	Credits	Prerequisite	Learning outcomes
Master [120] in Physical Engineering	FYAP2M	6		🔍
Bachelor in Physics	PHYS1BA	6		🔍