UCLouvain

lphys1344 — subatomic, atomic and molecular physics

2019

In view of the health context linked to the spread of the coronavirus, the methods of organisation and evaluation of the learning units could be adapted in different situations; these possible new methods have been - or will be - communicated by the teachers to the students.

6 credits	45.0 h + 45.0 h	Q2

Teacher(s)	Lauzin Clément ;Lemaitre Vincent ;Urbain Xavier ;
Language :	French
Place of the course	Louvain-la-Neuve
Prerequisites	LPHYS1241 or equivalent teaching unit from another programme. Having followed LPHYS1342 and having followed and passed LPHYS1231 are assets. *The prerequisite(s) for this Teaching Unit (Unité d'enseignement – UE) for the programmes/courses that offer this Teaching Unit are specified at the end of this sheet.*
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.
Aims	**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; 1 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); 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. - - - - *The contribution of this Teaching Unit to the development and command of the skills and learning outcomes of the programme(s) can be accessed at the end of this sheet, in the section entitled "Programmes/courses offering this Teaching Unit".*
Evaluation methods	**Due to the COVID-19 crisis, the information in this section is particularly likely to change.** Written or oral exam, open and closed questions, short or long-term developments. Problem solving with encrypted result.
Teaching methods	**Due to the COVID-19 crisis, the information in this section is particularly likely to change.** The learning activities consist of lectures, exercises, practical work, software manipulations and database consultations. The pedagogical material for the lectures are the blackboard and 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 physics. The practical work sessions aim to learn how to use the ideas and formalism developed in nuclear, atomic and molecular physics to explain the results of laboratory experiments, to choose and use computational methods for their analysis, and to interpret the obtained results. The laboratories 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 observation made in the laboratory.
Content	I. **Introduction and discovery of the elementary constituents of the atom and introduction to different experimental techniques** (hourly volume of 7h). 1.1 Subatomic, atomic and molecular physics and cosmological connection. 1.2 Review of some principles of experimental techniques. 1.3 Star Spectra and X-rays . 1.4 Discovery of the nucleus and the electron. **II. Atomic physics**. (hourly volume of 12h). 2.1 Explanation of the structure of atoms and ions based on a brief review of the results of quantum physics and spectroscopy. 2.2 Hydrogen-like systems, quantum defect, Rydberg states. 2.3 Multi-electron systems: Hartree-Fock method. 2.4 Central field and corrections, coupling schemes, isoelectronic series. 2.5 Radiative transitions, dipole approximation, multipolar transitions, selection rules, radiative cascades. 2.6 Stark effect and atomic polarizability, negative ions. **III Molecular physics** (hourly volume of 12h). 3.1 The Born-Oppenheimer approximation. 3.2 Separation of coordinates. 3.3 Electronic states: molecular orbitals and atomic orbitals. 3.4 Vibrational states and rotational states. 3.5 Symmetries of diatomic molecules. 3.6 Correlation diagrams. 3.7 Radiative transitions, selection rules. **IV Nuclear physics** (hourly volume of 14h). 4.1 Discovery of the neutron, the first nuclei and concept of isospin strong. 4.2 Introduction to Feynman diagrams. 4.3 Discovery of radioactivity and cosmic radiation (origin and composition). 4.4 Model of the liquid drop. 4.5 Yukawa model of the interaction between nucleons. 4.6 Discoveries of the pawn and the muon. 4.7 Layered nuclear models (Woods-Saxon potential). 4.8 More complete description of alpha, beta and gamma decays. 4.9 Introduction to fusion and nuclear fission.

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.
Faculty or entity in charge	PHYS

Programmes containing this learning unit (UE)

Program title	Acronym	Credits	Prerequisite	Aims
Master [120] in Physical Engineering	FYAP2M	6		🔍
Bachelor in Physics	PHYS1BA	6	LPHYS1241	🔍
Minor in Physics	LPHYS100I	6	LPHYS1241	🔍