12998-352(8) Atomic- and Nuclear Physics (1½ ℓ, 1½ p)

2017

Course summary:

Magnetic dipole moments, spin-orbit coupling, radiation transition rates, Zeeman effect, Helium atom. Nuclear structure and properties, radioactive decay, the nuclear force, introduction to nuclear models, apparatus of nuclear physics, elementary particles.

Method of assessment: Flexible assessment

Prerequisite modules: Physics 254, 334

Language policy:

Afrikaans and English in the same class groups:
During each lecture, all information is conveyed at least in English. Summaries and/or explanation of the core concepts will also be given in Afrikaans. Questions in Afrikaans and English will, at the least be answered in the language of the question. Students will be supported in Afrikaans and English during a combination of appropriate facilitated learning opportunities.

Module relevance in programme:

The Physics 352 module is an integral part of a complete BSc degree in Physics.

Research in modern atomic physics relies on sophisticated control of atom dynamics. This allows both the development of high-tech applications such as atomic clocks or atom based quantum computers, as well as deep probing of the fundamental laws of physics. The course gives a basic overview of atomic structure, and then studies both coherent and dissipative interactions between atoms and light or static fields, with a focus on how these interactions can be exploited to control atom dynamics. The course is a precursor to the honours course in atomic physics which focuses on developing a detailed understanding of atomic structure. Many of the concepts studied will be useful for students interested in doing research in either theoretical of experimental laser physics, quantum optics, atomic physics, quantum metrology or quantum information processing.

In conjunction with the Atomic Physics section, the Nuclear Physics part of this module aims to equip final year students with the skills and techniques related to fundamental principles in Nuclear Physics such as nuclear structure, nuclear stability and decay, binding energy, cross sections and nuclear reaction mechanisms.

Building on prior knowledge of Quantum Mechanics and Electromagnetism, this introductory Nuclear Physics course is an important foundation for further postgraduate studies in, not only Nuclear Physics, but also Radiation and Health, Laser and Theoretical Physics honours programmes.

Outcomes of course:

I. **Atomics Physics**
Students are skilled on an introductory level in the theoretical modelling of atomic structure and its correspondence with experimental observation. It also serves as a unified application of quantum mechanical techniques, classical electromagnetism and mechanics as well as optics in order to describe the internal structure of atoms.

II. **Nuclear Physics**
Students are equipped with a basic knowledge of nuclear physics.

Lecturers:

Dr. H. Uys (Atomic Physics)
Telephone number: (021) 808-3371
E-mail address: hermann@sun.ac.za
Office: Room number 1046 in the Merensky Physics Building.

Dr. JJ van Zyl (Nuclear Physics)
Telephone number: (021) 808-3384
E-mail address: jjvz@sun.ac.za
Office: Room number 1016 in the Merensky Physics Building.

Mentor:

The Department of Physics has appointed a staff member as mentor for each year of its physics programme to be available to students for consultation. Students should feel free to discuss general issues related to the physics programme or specific modules in the programme with the relevant mentor, in addition to usual consultations with their individual lecturers of modules.

The mentor for third year programme and its modules is Dr CM Steenkamp cmsteen@sun.ac.za

Course content:

I. **Atomic Physics - 9 (50minute) Lectures**
This is an introductory course in Atomic Physics. The quantum mechanical description of one electron atoms leads to the set of allowed radial eigenfunctions and the spherical harmonics with associated eigenvalues and the gross structure in the hydrogenic energy level scheme. Probability densities, quantised orbital angular momentum and associated magnetic dipole moments are discussed. The Stern-Gerlach experiment and introduction of electron spin is covered. Spin-orbital interaction leading to the lifting of the orbital angular momentumdegeneracy and the fine structure in the spectrum is discussed. Radiational transitions are covered in an extremely rudimentary fashion. The Zeeman effect is discussed. This is followed by treating the two-electron atom and the case of identical half-integer spin particles and the Pauli exclusion principle.

II. **Nuclear Physics - 9 (50 minute) Lectures**
Nuclear structure and properties, nuclear stability, partial decay constants, radioactive series, multipole radiation, nuclear reaction mechanisms, magnetic moment, electrical quadrupole moment, introduction to nuclear models, nuclear energy.

Detailed Contents of Atomic Physics

a. **Level structure of atoms with one and two valence electrons**
What is modern atomic physics, Overview of the hydrogen atom, Energy spectrum including fine and hyperfine structure, Rules for adding orbital angular momenta, Multi-electron atoms: configurations, terms, levels and states, Radiative transitions and selection rules

b. **Atom-light interaction**
Dipole coupling, Optical Bloch Equations, Scattering cross-section, Saturation intensity, AC-Stark shift

c. **Laser cooling and trapping**
Scattering force, Optical molasses, Doppler cooling limit, optical dipole force

d. **Atomic clocks**
Definition of the second, Ramsey interferometry, atomic clock protocols

Detailed Contents of Nuclear Physics

1. **Introduction:**
   Historical review;; Occurrence of nuclei; Sizes of nuclei; Atomic masses; Binding energy; Angular momentum and parity; Excited states of nuclei.

2. **Radioactivity and disintegration:**
   Radioactive decay; Occurrence of radioactivity; Conservation laws for radioactive decay; Properties of neutrinos; Gamma decay and internal conversion;

3. **Nuclear reactions:**
   Cross sections in nuclear reactions; Reaction mechanisms; Rutherford scattering

4. **Other nuclear properties:**
   Magnetic dipole moment; Electric quadrupole moment; Isospin.

5. **Nuclear models:**
   The strong interaction between nucleons; Liquid drop model; Fermi gas model; Shell model; Collective model.

Practical (Tutorials):

Tutorial sessions are used for assistance in problem solving in this course.

Study material:

For atomic physics section: Text book: Atomic Physics, C.J. Foot

Learning opportunities:

Lectures as per time table

Assessment:

Methods of Assessments
Continuous assessment

Venue and time of assessment opportunities
Assessments are conducted during contact sessions. Also see timetable.

Calculation of final mark for the module:
4 or more assessments counting a maximum 25% each. Final module mark comprised of equal contributions of Atomic Physics and Nuclear Physics parts.

Admission to examination:
Not applicable.