# 12998 - 352 (8) Application of Quantum Mechanics (1.5L, 1.5P)

## 2020

### Course summary:

Magnetic dipole moments, spin-orbit coupling, radiation transition rates, Zeeman effect. Electrons in periodic crystal potentials. Nuclear structure and properties, radioactive decay, nuclear scattering.

*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 the basic terminology and skills commonly used in introductory nuclear physics. This section of the course also connects to more general physics principles

of conservation laws, exponential decay, and quantum mechanical concepts such as angular momentum, spin and energy quantisation.

## Lecturers:

**Dr.** CM Steenkamp **(Atomic Physics)**
Telephone number: (021) 808-3374
E-mail address: cmsteen@sun.ac.za
Office: Room number 1044 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 GW Bosman** gwb@sun.ac.za

## Course content:

I. **Atomic Physics - 9 (50 minute) Lectures**
This is an interoductory course in Atomic Physics buidling on the solutions of the wave functions of the hydrogen atom that has been discussed in Quantum Physics. The principles are extended to multi-electron atoms with 1 or two valence electrons, spin-orbit coupling and the interaction between the magnetic dipole of an atom and an external magnetic field (Zeeman effect). We study the theoretical description of atom-radiation interaction with damping, the population dynamics of a two-level atom (Rabi oscillations). We consider the rates of transition by means of radiation, the absorption of light of low and high intensities. We discuss several ways to cool, trap and manipulate atoms using light - as used in cutting-edge technology and quantum computers.

II. **Nuclear Physics - 9 (50 minute) Lectures**
We start with a brief overview of the relevant terminology, and size and energy scales common in Nuclear Physics. The fundamental concepts of nuclear masses, binding energies and Q-values are introduced in the context of nuclear matter distributions and the liquid-drop model. We study the primary nuclear decay mechanisms and the radioactive decays laws as it is used in activity calculations and applications such as radioactive dating. We look further at nuclear stability from the Fermi-gas model. The basic concepts of nuclear reactions, energy conservation and reaction cross sections are introduced by means of the classical example of Rutherford scattering. We focus on the nuclear shell model to describe the nuclear potential, and the ground state spins and parities of nuclei.

### *Detailed Contents of Atomic Physics*

**a.** Atomic structure: The hydrogen atom, angular momentum coupling, fine structure and hyperfine structure, the Zeeman effect. Examples of atoms with one or two valence electrons, LS coupling, Pauli's exclusion principle, exchange energy. Selection rules for dipole transitions.

**b.** Atom radiation interaction: The interaction Hamiltonian, Rabi Oscillations, the Bloch vector and Bloch sphere, AC Stark effect and dressed states, radiative damping.

c. Absorption of light by atoms: The optical absorption cross-section, saturation intensity, power broadening.

**d.** Laser cooling and trapping of atoms: The scattering force, the Zeeman slower, optical molasses. The dipole force and optical lattices.

***Detailed Contents of Nuclear Physics***

1. **Introduction:**
   The Standard Model, energy scales, labelling; Nuclear masses, Binding Energies, Q-value; The Liquid Drop model, nuclear charge distribution and the Semi-empirical mass formula (SEMF).

2. **Radioactivity and disintegration:**
   Conservation laws, Alpha, Beta and Gamma Decay; Radioactive Decay Laws, Radioactive dating; Nuclear stability and the Fermi-gas model.

3. **Nuclear reactions:**
   Direct and Compound Nuclear Reactions, Reaction kinematics; Classical description of Rutherford scattering, Cross Section.

4. **Nuclear** Shell **model:**
   The Nuclear Force, Magic Numbers; Shell Model, Woods-Saxon potential, Spin-orbit Interaction, Spin and Parity of ground states, Excited States.

## Practical (Tutorials):

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

## Study material:

Class notes and several reference texts are supplied or suggested by the lecturers.

## 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.

***Admission to examination:***
Not applicable.