PH4042 - Concepts in Atomic Physics and Magnetic Resonance

Credits: 15  Semester: 2
Number of Lectures: 27  Lecturer: Dr Donatella Cassettari, Dr Peter Wahl,
                             Dr Graham Smith and Dr Janet Lovett
Academic Year: 2016-17

Overview
This module builds on the atomic physics covered in PH4041 to look at the atomic structure of helium and many-electron atoms, magnetic interactions within the atom (leading to fine and hyperfine splitting), the Zeeman effect, and topics in atom-light interaction. These well-established concepts are then used in contemporary topics such as cold atom physics and magnetic resonance, both of which are current research topics within the School.

Aims & Objectives
This module introduces the effects of magnetic fields on the energy levels of atoms, starting with the alkali atoms, but then generalizing the concepts to atoms with multiple electrons. It will be discussed how these effects can be measured as well as their importance for modern concepts in atomic physics, such as magnetic resonance and quantum optics (laser cooling, laser spectroscopy). It therefore serves to bridge between a basic knowledge of atomic physics established in PH4041 and modern research topics.

Learning Outcomes
By the end of the module, students will have a comprehensive knowledge of the topics covered in the lectures. In particular they will be able to

- Explain the influence of a magnetic field on the spectrum of an atom
- Understand the interplay between spin-orbit coupling, hyperfine coupling and magnetic field and their influence on the spectrum.
- How the energy spectrum of atoms with multiple electron can be obtained, qualitatively and quantitatively
- Explain how the spectrum of atoms can be probed in laser spectroscopy, and how this can be used for laser cooling and to achieve Bose-Einstein condensation
- Understand the basic concepts and applications of magnetic resonance (EPR, NMR, MRI)
- Explain the basic pulse sequences and techniques used in magnetic resonance
- Explain how magnetic resonance imaging works
- Explain how NMR and EPR can be used to determine molecular structure

Synopsis
The material to be covered is planned to be along the following lines and timing, but there may be changes made from this schedule.
Week 1 - Brief recapitulation of spin-orbit coupling in alkali atoms. Interaction with an external magnetic field: the anomalous Zeeman effect.
Week 2 - Probing the Zeeman effect of single atoms by STM. The Paschen-Back effect.
Week 3 - Hyperfine structure of spectral lines. From one-electron to many-electron atoms: helium.
Week 5 - Introduction to atom-light interaction. Monochromatic radiation and the Bloch equations.
Week 6 - Concepts in laser spectroscopy.
Week 7 - Cold atom physics and its applications.
Week 8 - Basic concepts in magnetic resonance (spin, population, coherence). Relaxation (T1 and T2 and Bloch Equations). Cw and pulse techniques and Fourier Transform concepts
Week 9 - Free induction decay, Hahn echo, stimulated echo + 2 dimensional concepts. Liquid state NMR (How does it work and main applications). Solid state NMR (How does it work and main applications)
Week 10 - Quantum mechanical aspects of magnetic resonance. Liquid state NMR, Solid State NMR.
Week 11 - EPR (How does it work and main applications / concepts). MRI (How does it work - and main applications / concepts). Revision/Tutorial Lecture.
Pre-requisites
Before taking this module you must pass PH3061 Quantum Mechanics 1 and pass PH3062 Quantum Mechanics 2. A pass in PH4041 Atomic, Nuclear, and Particle Physics is required or special permission sought from both the module coordinator and the SH physics and astronomy adviser of studies.

Anti-requisites
PH4037 Physics of Atoms

Assessment
Continuous Assessment = 20%, 2 Hour Examination = 80%

Additional information on continuous assessment etc.
Most weeks of the semester reading will be set from classic papers in the field, good websites, texts, etc. This will be relevant to the material being covered in lectures. Students will on most weeks be asked to answer a number of questions associated with the readings, with short written answers expected. The questions will probe student comprehension of, and ability with, material in the reading.

Accreditation Matters
This module may not contain material that is part of the IOP “Core of Physics”, but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP “Graduate Skill Base”.

Recommended Books
The Physics of Atoms and Quanta: Introduction to Experiments and Theory - H. Haken, W. D. Brewer
2005
Please view University online record:
http://resourcelists.st-andrews.ac.uk/modules/ph4042.html

General information
Please also read the general information in the School’s honours handbook.