Nanyang Technological University
Division of Physics and Applied Physics

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| **Academic Year** | AY1819 | **Semester** | 2 |
| **Course Coordinator** | Rainer Dumke | | |
| **Course Code** | PH3401 | | |
| **Course Title** | Atomic Physics | | |
| **Pre-requisites** | PH3101 | | |
| **No of AUs** | 4 AU | | |
| **Contact Hours** | 3 hr lecture, 1 hr tutorial | | |
| **Proposal Date** | 04/12/2018 | | |

**Course Aims**

Atomic physics is fundamentally important in physics. It is a direct application of the quantum mechanical framework. It extends the understanding quantum mechanics and underlines its importance. Atomic physics introduces the fundamental concepts which are also applicable in condensed matter / nuclear / molecular physics.

**Intended Learning Outcomes (ILO)**

By the end of this course, you (as a student) would be able to:

Basics: Energy scales, masses and sizes / Isotopes and the Nucleus / Photons and Electrons (BAS)

1. Describe which energy and length scales are relevant for effects determining the atomic spectrum. Discuss the differences in the mass distribution in the atom. Formulate how to measure the size and the mass of an atom.
2. Derive the effect of the nuclear mass on the energy spectrum of an Atom. Identify methods how to separate isotopes.
3. Derive the black body radiation spectrum.
4. Formulate the wave particle dualism and explain the interference patterns in electron optics.

Basic Quantum Mechanics: Concept of Matter waves / Bohr Model / Magnetic Moment and Spin (QM)

5. Formulate a wave function expressing the matter wave characteristics.
6. Derive the Heisenberg principle, and the energy time uncertainty.
7. Explain the gross structure of Hydrogen atoms and formulate the atomic level energy scaling.
8. Formulate the electron spin using special relativity and derive the magnetic moment and the gyro magnetic ratio.

Higher Order Corrections: Fine structure / Hyperfine structure / Lamb shift (HOC)

9. Derive the fine structure splitting and associated shift from relativistic corrections.
10. Calculate the Hyperfine splitting.
11. Discuss the origin and consequences of the Lamb shift.

Behaviour of atoms in external fields: magnetic / electric / optical transitions (EF)

12. Derive the Energy correction due external fields (e.g weak, intermediate and strong magnetic fields and electric fields)
13. Identify and derive the selection rules for optical transitions.

Pauli Principle and with this the Helium spectrum (PP)

14. Derive the Pauli Principle.

15. Formulate symmetric and anti-symmetric wave functions.
16. Identify singlet and triplet states.
17. Describe the Helium Spectrum.

Many Electron Atoms (MEA)

18. Extend the Pauli Principle to multi-electron atoms and describe the ground state electron configuration for multi-electron atoms.
19. Discuss the periodic table.

**Course Content**

Energy scales / mass and size
Isotopes and Nucleus
Photons / Electrons / Matter waves
Bohr Modell of Hydrogen / Basic QM
Magnetic Moment, Spin
Fine Structure Lamb Shift
Hyperfine structure
Atoms in external fields: magnetic
Atoms in external fields: electric
Optical transitions
Helium / Pauli Principle
Many Electron Atoms

**Assessment (includes both continuous and summative assessment)**

| Component | Course LO Tested | Related Programme LO or Graduate Attributes | Weighting | Team/Individual | Assessment Rubrics |
|---|---|---|---|---|---|
| 1. Presentation: Course Related Topic | All | Competence (1,2,3,4,5) Creativity (2) Communication (1) | 20% | Individual | See Appendix 1 |
| 2. Report (with Viva): Course Related Topic | All | Competence (1,2,3,4,5) Creativity (2) Communication (1) | 35% | Individual | See Appendix 2 |
| 3. Term Test 1 | All | Competence (1,2,3,4,5) Creativity (2) Communication (1) | 15% | Individual | Point-based marking |
| 4. Term Test 2 | All | Competence (1,2,3,4,5) Creativity (2) Communication (1) | 15% | Individual | Point-based marking |
| 5. Continuous Assessment: Home Work | All | Competence (1,2,3,4,5) Creativity (2) Communication (1) | 15% | Individual | Point-based marking |
| Total | | | 100% | | |

**Formative feedback**

Formative feedback is given through discussion within tutorial lessons, a discussion after the midterms, a discussion after the presentation and viva and an examiner's report for the term tests.

**Learning and Teaching approach**

| Approach | How does this approach support students in achieving the learning outcomes? |
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| Lectures | The lectures build up the central concepts of the course, and provide concrete examples for calculations of the type and difficulty students are expected to be able to do. |
| In-class quizzes | The in-class quizzes provide practice problems for the topics covered during the lectures in the current week, allowing students to apply and practice their newly-acquired knowledge. Usually these problems are done in small groups to encourage peer learning. Feedback is provided directly to the individual groups. |
| Presentation/Report | The students select a research topic of interest, and perform an in-depth study of the topic, culminating in a project presentation and report. This develops the ability to apply newly learned the principles to new topics and scenarios. |

**Reading and References**

"The Physics of Atoms and Quanta"; Hermann Haken, Hans Wolf Atomic Physics ; Available via the library online
"Atoms, Molecules and Photons"; Wolfgang Demtröder ; Available via the library online

**Course Policies and Student Responsibilities**

*<u>Example for a course using Team-based Learning:</u>*

***(1) General***

*Students are expected to complete all assigned pre-class readings and activities, attend all seminar classes punctually and take all scheduled assignments and tests by due dates. Students are expected to take responsibility to follow up with course notes, assignments and course related announcements for seminar sessions they have missed. Students are expected to participate in all seminar discussions and activities.*

***(2) Absenteeism***

*TBL requires you to be in class to contribute to team work. In-class activities make up a significant portion of your course grade. Absence from class without a valid reason will affect your overall course grade. Valid reasons include falling sick supported by a medical certificate and participation in NTU's approved activities supported by an excuse letter from the relevant bodies. There will be no make-up opportunities for in-class activities.*

*If you miss a seminar session, you must inform your team members and me via email (include email address) prior to the start of the class. Students who miss T-RATs and team in-class activity with* *valid reasons will earn the team score. Students who miss I-RAT or T-RAT without a valid reason will earn nothing for that session of absence.*

*For I-RAT scores, we will consider the best of ten I-RATs out of twelve I-RATs. This method will take care of students who miss classes with valid reasons. Students, who miss I-RATs more than twice with valid reasons, may be asked to take a separate test.*

**Academic Integrity**

Good academic work depends on honesty and ethical behaviour. The quality of your work as a student relies on adhering to the principles of academic integrity and to the NTU Honour Code, a set of values shared by the whole university community. Truth, Trust and Justice are at the core of NTU's shared values.

As a student, it is important that you recognize your responsibilities in understanding and applying the principles of academic integrity in all the work you do at NTU. Not knowing what is involved in maintaining academic integrity does not excuse academic dishonesty. You need to actively equip yourself with strategies to avoid all forms of academic dishonesty, including plagiarism, academic fraud, collusion and cheating. If you are uncertain of the definitions of any of these terms, you should go to the academic integrity website for more information. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

**Course Instructors**

| Instructor | Office Location | Phone | Email |
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| Rainer Dumke | SPMS-PAP-04-16 | | rdumke@ntu.edu.sg |

**Planned Weekly Schedule**

| Week | Topic | Course LO | Readings/ Activities |
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| 1 | Introduction / energy scales / mass and size | BAS 1 | Haken Wolf Chapter 2 (HW 2) Lecture |
| 2 | Isotopes and Nucleus / Photons | BAS2-3 | HW 3,4,5; Lecture Homework |
| 3 | Electrons / Matter waves | BAS 4; QM 5 | HW 6,7; Lecture |
| 4 | Bohr Model of Hydrogen / Basic QM | QM 6-7 | HW8; Lecture |
| 5 | Hydrogen atom / Magnetic Moment, Spin | QM 8 | HW 10,12; Lecture Homework |
| 6 | Fine Structure Lamb Shift/ Hyperfine structure | HOC 9-11 | HW 12,20; Lecture |
| 7 | Atoms in external fields: magnetic | EF 12 | HW 13,14; Lecture |
| 8 | Atoms in external fields: electric | EF 12 | HW 15 ; Mid Term Exam; Lecture |
| 9 | Optical transitions | EF 13 | HW 16 ; Lecture ; Homework |
| 10 | Helium / Pauli Principle | PP 14-17 | HW 17; Lecture |
| 12 | Many Electron Atoms | MEA 18 19 | HW19; Lecture; Homework |

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| 13 | Modern Experiments / Revision | Revision | End Term; Lecture |
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**Appendix 1:**

**Project Presentation Rubrics** (Adapted and modified from PH2102)

| Criteria | Exceeds Standard (10 – 9) | Meets Standard (8.5 – 6) | Almost Meets Standard (5.5 – 3.5) | Does not meet standard (3 – 0) |
|---|---|---|---|---|
| **Organization** | The content is presented in a clearly defined order making it possible to easily follow the logic of the presentation. | The content is presented in a defined order making it possible to follow the logic of the presentation. | The content is presented somehow structured, however there are clear jumps in the context without further bridging comments/slides. | The presentation has no clear logical structure. |
| **Scientific communication** | Communicates difficult or complex ideas in an effective and understandable manner | Communicates ideas in an effective and understandable manner | Communicates ideas somewhat effectively, which are mostly understandable. | Does not communicate ideas effectively. |
| **Scientific Understanding** | Understands the topic beyond textbook knowledge and can answer open end questions. | Understands the topic within textbook knowledge and can answer well defined questions. | Understands the topic within textbook knowledge. | Does not understand topic. |
| **Scientific Argumentation / Discussion** | During the QA session the candidate argued logical and scientifically correct. | The argumentation was scientifically correct but had some minor parts missing. | The argumentation was mostly scientifically correct. | The candidate had difficulties in answering the questions. His argumentation was disconnected and not logical. |

**Appendix 2:**

**Report Rubrics** (Adapted and modified from https://www.cte.cornell.edu/documents/Science%20Rubrics.pdf and PH2102)

| Criteria | Exceeds Standard (10 – 9) | Meets Standard (8 – 6) | Almost Meets Standard (5.5 – 3.5) | Does not meet standard (3 – 0) |
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| **Problem or Research Statement** | Clearly and accurately communicated, and gives background or context and motivation. | Clearly and accurately communicated. | Somewhat unclear or unable to accurately portray the problem. | Unclear and inaccurate or illogical statement. |
| **Correct and appropriate physics** | Correct and appropriate use of physics, with assumptions, approximations, experimental | Correct and appropriate use of physics, with some clarity on assumptions, approximations, | Mostly correct and appropriate use of physics. | Incorrect or inappropriate use of physics in most areas. |

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| | techniques, and derivations that are accurate and detailed. | experimental techniques, and derivations. | | |
| **Scientific Approach** | Appropriate and addresses the problem from multiple perspectives. | Appropriate and address the problem from a single perspective. | Somehwat appropriate, and addresses an incomplete subset of the problem. | Inappropriate or illogical, and does not address the problem. |
| **Significance of Results and Conclusions** | Presents a logical and complete explanation for findings and addresses most of the questions. Ends with logical, effective and relevant conclusion | Presents a logical explanation for findings and addresses some of the questions. Ends with coherent conclusion based on evidence. | Presents an incomplete explanation for findings and addresses few questions. Ends with a conclusion based on evidence. | Presents an incomplete or wrong explanation for findings and does not address any of the questions. Ends without a conclusion. |
| **References and Citations** | Proper, accurate and clear citations and attribution of others' work. | Proper, accurate and clear citations and attribution of others' work. | Proper and clear citations and attribution of others' work, with minor errors. | Proper and clear citations and attribution of others' work, with major errors. |
| **Development of Ideas** | Introduces the topic clearly and creatively. Maintains clear focus on the topic. Development of and connection between ideas are clear and correct. | Introduces the topic clearly. Maintains focus on the topic. Development of and/or connection between ideas are clear and correct. | Introduces the topic. Somewhat maintains focus on the topic. Development of some ideas are clear. | Does not clearly introduce the topic. Does not establish or maintain focus on the topic. |

**The main presentation should include:**
• a ***presentation*** of the appropriate ***concepts, theories and principles*** of the problem
• an ***explanation*** of the ***observed phenomena***
• an ***application*** of ***appropriate mathematics***
• linking of ***theoretical*** and ***experimental findings*** to draw ***suitable conclusions***
• an attempt to communicate ***difficult*** or ***complex*** ideas in an ***effective*** and ***understandable*** manner

**Student participation:**
As far as possible, all students in the group should participate in the presentation or Q&A, so that it is possible to give a grade for each student.

**Duration:** Presentation (approx. 20 min) + Q&A (approx.10min) = Total of approx. 30 min.

***What we want our graduates from Physics and Applied Physics to be able to do:***

Upon the successful completion of the PHY, APHY and PHMA programs, graduates should be able to:

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| *Competency* | 1 | demonstrate a rigorous understanding of the core theories and principles of physics involving (but not limited to) areas such as classical mechanics, electromagnetism, thermal physics and quantum mechanics<br><br>[PHMA only] demonstrate a rigorous understanding of the core theories and principles of mathematical sciences involving (but not limited to) areas such as analysis, algebra and statistical analysis |
| | 2 | read and understand undergraduate level physics content independently; |
| | 3 | make educated guesses / estimations of physical quantities in general; |
| | 4 | apply fundamental physics knowledge, logical reasoning, mathematical and computational skills to analyse, model and solve problems; |
| | 5 | develop theoretical descriptions of physical phenomena with an understanding of the underlying assumptions and limitations; |
| | 6 | critically evaluate and distinguish sources of scientific/non-scientific information and to recommend appropriate decisions and choices when needed; |
| | 7 | demonstrate the ability to design and conduct experiments in a Physics laboratory, to make measurements, analyse and interpret data to draw valid conclusions. |

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| *Creativity* | 1 | propose valid approaches to tackle open-ended problems in unexplored domains; |
| | 2 | offer valid alternative perspectives/approaches to a given situation or problem. |

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| *Communication* | 1 | describe physical phenomena with scientifically sound principles; |
| | 2 | communicate (in writing and speaking) scientific and non-scientific ideas effectively to professional scientists and to the general public; |
| | 3 | communicate effectively with team members when working in a group. |

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| *Character* | 1 | uphold absolute integrity when conducting scientific experiments, reporting and using the scientific results; |
| | 2 | readily pick up new skills, particularly technology related ones, to tackle new problems; |
| | 3 | contribute as a valued team member when working in a group. |

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| *Civic Mindedness* | 1 | put together the skills and knowledge into their work in an effective, responsible and ethical manner for the benefits of society. |