Annexe A: New/Revised Course Content in OBTL+ Format

Course Overview

Expected Implementation in Academic Year (New format)	AY2026-2027
Semester/Trimester/Others (specify approx. Start/End date)	Semester 1
Course Author * Faculty proposing/revising the course	Sum Tze Chien
Course Author Email	tzechien@ntu.edu.sg
Course Title	Nuclear Physics
Course Code	PH4408
Academic Units	3
Contact Hours	39
Research Experience Components	Not Applicable

Course Requisites (if applicable)

Pre-requisites	PH3101
Co-requisites	
Pre-requisite to	
Mutually exclusive to	
Replacement course to	
Remarks (if any)	

Course Aims

This course aims to provide a basic understanding of the structure of nuclei and their properties, with a strong focus on linking theory with experimental observations of nuclear behaviour. The course will provide an overview of the basic properties of the nucleus and its structure; introduce the nuclear models developed to explain the properties of the nucleus; aims to quantitatively describe the energy balances and spin/parity selection rules of alpha, beta and gamma decay processes in radioactivity; as well as to familiarize one with the applications of nuclear physics including fusion and fission. This course will thus equip you with the fundamental concepts that will provide you the foundation for advanced studies in nuclear physics and particle physics or prepare you to follow or initiate research in field or to work in industry jobs related to nuclear science and technology.

Course's Intended Learning Outcomes (ILOs)

Upon the successful completion of this course, you (student) would be able to:

ILO 1	Describe and discuss the fundamental nature of nuclei and nuclear phenomena.
ILO 2	Determine how models are constructed to explain phenomena and their limitations.
ILO 3	Employ quantitative analysis and reasoning skills to interpret nuclear phenomena.
ILO 4	Describe and discuss the physics of nuclear power generation – nuclear fission & nuclear fusion; radiation safety and shielding and environmental issues.
ILO 5	Nuclear Properties (NP1) Explain the difference between the nuclear charge and nuclear matter distributions and establish the empirical relationship between nuclear radius and mass number.
ILO 6	Nuclear Properties (NP2) Use basic classical mechanics concepts to derive the Rutherford Scattering formula and calculate the cross-sections.
ILO 7	Nuclear Properties (NP3) Explain the difference the between atomic mass and nuclear mass. Calculate the binding energy of nuclei. Describe the experiments to measure nuclear mass.
ILO 8	Nuclear Properties (NP4) Describe the properties of the nuclei (i.e., radius, binding energy, angular momentum, magnetic dipole moment, electric quadrupole moment, parity, etc.).
ILO 9	Nuclear Properties (NP5) Use basic quantum mechanical formalism, such as the time-independent Schrodinger equation in free space, to calculate charge densities and expectation values.
ILO 10	Nuclear Properties (NP6) Gain a better appreciation of advanced quantum mechanical concepts, such as ladder operators that are used to calculate the Clebsch-Gordan coefficients for simple examples of angular momentum addition.
ILO 11	Nuclear Structure (NS1) Use basic quantum mechanical formalism, such as the time-independent Schrodinger equation in free space, to solve for the Deuteron wavefunction and to calculate the charge and current densities
ILO 12	Nuclear Structure (NS2) Understand the intrinsic spin (S), orbital angular momentum (L), and total angular momentum (J) of individual nucleons. Quantify nuclear spin (I) and explain how individual orbital and spin momenta combine to determine the nucleus's observable properties, and apply conservation laws during nuclear reactions.
ILO 13	Nuclear Structure (NS3) Explain the formation a bound deuteron state from the findings of the neutron-proton, proton-proton and neutron-neutron scattering experiments using the concepts of scattering length and effective range.

ILO 14	Nuclear Structure (NS4) Explain the properties of the nuclear force and describe the various contributions to the nuclear potential and the exchange force model.
ILO 15	Models of Nucleus (MoN1) Explain the underlying principles and assumptions taken in the formulation of the different models of the nucleus (e.g., Liquid Drop Model) as well as their strengths and limitations.
ILO 16	Models of Nucleus (MoN2) Use statistical mechanics to determine the density of states and solve for the Fermi energy and derive an expression of the total binding energy in the Fermi Gas model and relate to the asymmetry term in the Liquid Drop Model.
ILO 17	Models of Nucleus (MoN3) Describe the significance of the nuclear spin orbit term in determining the magic numbers in the shell model.
ILO 18	Models of Nucleus (MoN4) Determine the nuclear spin and parity assignments of the ground state of nuclei using the Shell Model as well as to interpret the spin and parity assignments of low-lying excites states of nuclei.
ILO 19	Models of Nucleus (MoN5) Describe how the features of low-lying excited states in even N - even Z nuclei are associated with collective behavior of the nucleons in the nucleus.
ILO 20	Radioactivity (R1) Explain the key concepts of the decay law, half-life, decay constants and activity as well as the application of radioactive dating methods.
ILO 21	Radioactivity (R2) Explain the key concepts in alpha decay and apply the spin and parity selection rules to determine the spin and parity assignments following alpha decay. Determine the energetics in the decay and calculate the Q value. Use basic quantum mechanical formalism to derive the transition probabilities in alpha decays and calculate the half-life.
ILO 22	Radioactivity (R3) Explain the key concepts in beta decay and the discovery of the neutrino. Determine the energetics in the decay and calculate the Q value. Use basic quantum mechanical formalism to derive the transition probabilities in beta decay. Explain the concept of comparative half-life.
ILO 23	Radioactivity (R4) Apply the spin and parity selection rules to determine the spin and parity assignments following beta decay. Explain the concepts of allowed and forbidden decays. Describe the parity violation experiment in Beta decay and the KATRIN experiment to determine the mass of the neutrino.
ILO 24	Radioactivity (R5) Describe the key concepts in alpha decay and apply the spin and parity selection rules to determine the spin and parity assignments following alpha decay. Determine the energetics in the decay and calculate the Q value. Use electromagnetic concepts to derive the transition probabilities in gamma decay; and calculate the half-life. Explain the concept of Weisskopf estimates.
ILO 25	

	Detection of Radiation (DoR1) Describe the interaction of alpha, beta and gamma radiation with matter and explain their energy loss mechanisms.
ILO 26	Detection of Radiation (DoR2) Explain the concepts of range, mean range, straggling, and stopping power.
ILO 27	Detection of Radiation (DoR3) Use of the Monte-Carlo software SRIM and CASINO to calculate the ranges of ions and electrons in matter.
ILO 28	Detection of Radiation (DoR4) Describe the basic operating principles of various detectors e.g., ionization chambers, scintillation detectors, solid state detectors, as well as the electronics used in nuclear spectroscopy.
ILO 29	Particle Accelerators (PA1) Describe the main features and basic operating principles of various particle accelerators: Cockcroft Walton, Van de Graaff, Tandem accelerator, Cyclotron, Synchrocyclotron, Isochronous Cyclotron, Synchrotron, Linear accelerator.
ILO 30	Particle Accelerators (PA2) Describe the applications of accelerators in medical physics, materials characterization, and high energy physics and explain concepts like Bragg peak for on therapy.
ILO 31	Nuclear Fission & Fusion (NF1) Explain why nuclear fission occurs and determine the energetics and the probability of spontaneous fission.
ILO 32	Nuclear Fission & Fusion (NF2) Describe the insights gained from the liquid drop model and calculate the energy released.
ILO 33	Nuclear Fission & Fusion (NF3) Describe the properties induced fission and the related concepts of prompt neutrons, delayed neutrons, fission cross-sections.
ILO 34	Nuclear Fission & Fusion (NF4) Calculate the rates for chain reaction.
ILO 35	Nuclear Fission & Fusion (NF5) Describe the operation of Nuclear Power Stations & Uranium Enrichment and the development of fission weapons (little boy and fat man).
ILO 36	Nuclear Fission & Fusion (NF6) Explain why nuclear fusion occurs and determine the energetics and the probabilities of various fusion reactions.
ILO 37	Nuclear Fission & Fusion (NF7) Explain why the D-T reaction is chosen for realizing commercial fusion on earth.
ILO 38	Nuclear Fission & Fusion (NF8) Describe the properties fusion and the related concepts of Coulomb barrier, fusion cross-section and reaction rates; as well as the processes in Solar Fusion

ILO 39	Nuclear Fission & Fusion (NF9) Understand the critical parameters underpinning the Lawson's criteria and the triple product in nuclear fusion.
ILO 40	Nuclear Fission & Fusion (NF10) Describe the main features and basic operating principles of the tokamak (ITER), spherical tokamaks, Wendelstein stellerator and inertial confinement fusion (Laser Mégajoule and National Ignition Facility); and the development of thermonuclear weapons

Course Content

Nuclear Properties & Nuclear Structure	Properties of nuclei: radii, masses, abundances, binding energies, spins and electromagnetic moments, Rutherford scattering, deuteron, nucleon-nucleon scattering in terms of an exchange force.
Models of Nucleus	Semi-empirical mass formula, the Fermi gas model, shell model, liquid drop model with vibrational and rotational excitations, collective structure.
Radioactivity	Half-life; Alpha decay: Geiger-Nuttal Rule, selection rules; Beta decay: Selection rules, parity violation, Fermi theory, neutrinos; Gamma decay: Selection rules, multipole transitions, Weisskopf estimates.
Detection of Radiation	interaction of alpha, beta and gamma radiation with matter; ionization chambers, scintillation detectors, solid state detectors
Particle Accelerators	Cockcroft Walton, Van de Graaff, Cyclotron, Synchrocyclotron, Synchrotron, Linear accelerator.
Nuclear Fission & Fusion	Nuclear fission energetics, Nuclear fission reactors and nuclear power; Nuclear Fusion energetics, experimental Fusion reactors and inertial confinement.

Reading and References (if applicable)

1. K. S. Krane, Introductory Nuclear Physics, John Wiley & Sons (ISBN: 978-0-471-80553-3), 1991

2. D. J. Griffiths and Schroeter Darrell F, Introduction to Quantum Mechanics (3rd Edition), Cambridge University Press (ISBN: 97811081000342), 2018

Planned Schedule

Week or Session	Topics or Themes	ILO	Delivery Mode	Activities	Readings
1	Lecture 0 (1h): Introduction to Nuclear Physics and Course Administration, Lecture 1 (1h): Nuclear Radius, Lecture 2 (1h): Rutherford Scattering	NP 1, 2	In-person	Materials and "Food for thought" Quizzes	Textbook, Reading Materials
2	Lecture 3 (1h): Nuclear Mass and Binding Energy, Lecture 4 (1h): Nuclear Properties, Tutorial 1 (1h)	NP 3, 4-6	In-person	Materials and "Food for thought" Quizzes	Textbook, Reading Materials
3	Lecture 5 (1h): The Deuteron , Lecture 6 (2h): Nucleon-Nucleon scattering I	NS 1, 2	In-person	Materials and "Food for thought" Quizzes	Textbook, Reading Materials
4	Lecture 7 (2h): Nucleon-Nucleon scattering II, Tutorial 2 (1h)	NS 3	In-person	Materials and "Food for thought" Quizzes	Textbook, Reading Materials
5	Lecture 8 (1h): Properties of the Nuclear Force, Lecture 9 (1h): Nuclear Models I – Semi-empirical Mass Model & Fermi Model, Lecture 10 (1h): Nuclear Models II – Shell Model	NS 4, MoN 1-2, MoN 3-4	In-person	Materials and "Food for thought" Quizzes	Textbook, Reading Materials
6	Lecture 11 (1h): Nuclear Models III – Collective Model, Lecture 12 (1h): Decay Law, Tutorial 3 (1h)	MoN 5, R 1	In-person	Materials and "Food for thought" Quizzes	Textbook, Reading Materials

Week or Session	Topics or Themes	ILO	Delivery Mode	Activities	Readings
7	Lecture 13 (2h): Alpha Decay, Lecture 14 (1 h): Beta Decay I	R 2, R 2	In-person	Materials and "Food for thought" Quizzes	Textbook, Reading Materials
8	Lecture 15 (2h): Recap of Key Concepts (Week 1-7) and Beta Decay II, Tutorial 4 (1h)	R 4	In-person	Materials and "Food for thought" Quizzes	Textbook, Reading Materials
9	Lecture 16 (1.5h): Gamma Decay, Lecture 17 (1.5h): Detection of Nuclear Radiation	R 5, DoR 1-3	In-person	Materials and "Food for thought" Quizzes	Textbook, Reading Materials
10	Lecture 18 (2h) Detectors, Tutorial 5 (1h)	DoR 4	In-person	Materials and "Food for thought" Quizzes	Textbook, Reading Materials
11	Lecture 19 (1.5h): Accelerators I, Lecture 20(1.5h): Accelerators II	PA 1 – 2	In-person	Materials and "Food for thought" Quizzes	Textbook, Reading Materials
12	Lecture 22 (2h): Nuclear Fission , Tutorial 6 (1h):	NF 1-5	In-person	Materials and "Food for thought" Quizzes	Textbook, Reading Materials
13	Lecture 23 (2h): Nuclear Fusion, Lecture 24 (1h): Revision (recap of key concepts)	NF 6-10	In-person	Materials and "Food for thought" Quizzes	Textbook, Reading Materials

Learning and Teaching Approach

Approach	How does this approach support you in achieving the learning outcomes?
Pre-Lecture Reading	To encourage learners to take a more active role in the teaching and learning process. Background reading will help guide and assess the conceptual understanding of related fundamental content to enhance the teaching and learning in the lectures.
Lectures	Content and derivations, examples of problem solving and discussion of conceptual understanding.
Tutorial	Review and discussion of key concepts from lectures with TAs, by working through problems. The TAs will monitor and provide timely feedback.
Homework	Homework comprises of problems and standard textbook practice questions that are discussed during lectures allowing for formative assessment and feedback.
Term Tests	Assessment for Learning (Formative Support) - These term tests act as a diagnostic tool that actively shapes the learning process.

Assessment Structure

Assessment Components (includes both continuous and summative assessment)

No.	Component	ILO	Related PLO or Accreditation	Weightage	Description of Assessment Component	Team/Individual	Rubrics	Level of Understanding
1	Summative Assessment (EXAM): Final exam(Final Examination)	All		60		Individual	Analytic	Multistructural
2	Continuous Assessment (CA): Test/Quiz(CA1: Term-Test 1)	All		20		Individual	Analytic	Multistructural
3	Continuous Assessment (CA): Test/Quiz(CA2: Term Test 2)	From Nuclear Properties to Radioactivity		20		Individual	Analytic	Multistructural

Description of Assessment Components (if applicable)

Formative Feedback

Formative feedback is seamlessly integrated into the course to support continuous learning. On a weekly basis, interactive 'food for thought' questions during lectures and problem-solving exercises in tutorials provide immediate insights into your conceptual understanding. To ensure the course matches student needs, the teaching team meets weekly to evaluate student progress, adjusting the lecture pace and difficulty accordingly. The two term tests serve as progressive benchmarks of your learning; detailed feedback will be provided after each test to highlight common misconceptions and clarify core concepts. Additionally, past examination papers and examiners' reports are made available to facilitate independent self-assessment. For personalized guidance, the lecturer and the teaching assistant provide timely, one-on-one feedback via email, post-class discussions, and dedicated consultation hours.

NTU Graduate Attributes/Competency Mapping

This course intends to develop the following graduate attributes and competencies (maximum 5 most relevant)

Attributes/Competency	Level
Care for Environment	Intermediate
Learning Agility	Advanced
Critical Thinking	Advanced

Course Policy

Policy (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. On the use of technological tools (such as Generative AI tools), different courses / assignments have different intended learning outcomes. Students should refer to the specific assignment instructions on their use and requirements and/or consult your instructors on how you can use these tools to help your learning. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

Policy (General)

This course is built on the principle of Constructive Alignment. The lecturer's core mandate is to guide, support, and evaluate your progress toward achieving the Intended Learning Outcomes (ILOs) specified in this portal.

Policy (Absenteeism)

Absence Due to Medical or Other Reasons
If you are sick and unable to attend your class / Mid-terms, you have to:

1. Send an email to the instructor regarding the absence and request for a replacement class and make-up mid-terms.
2. Submit the original Medical Certificate* or official letter of excuse to administrator.
3. Attend the assigned replacement class (subject to availability) and make-up mid-terms.

* The medical certificate mentioned above should be issued in Singapore by a medical practitioner registered with the Singapore Medical Association.

Policy (Others, if applicable)

Diversity and inclusion policy

Integrating a diverse set of experiences is important for a more comprehensive understanding of science.

It is our goal to create an inclusive and collaborative learning environment that supports a diversity of perspectives and learning experiences, and that honours your identities; including ethnicity, gender, socioeconomic status, sexual orientation, religion or ability.

To help accomplish this:

- If you are neuroatypical or neurodiverse, have dyslexia or ADHD (for example), or have a social anxiety disorder or social phobia;
- If you feel like your performance in the class is being impacted by your experiences outside of class;
- If something was said in class (by anyone, including the instructor) that made you feel uncomfortable;

Please speak to your teaching team, our school pastoral officer or a peer or senior (either in-person or via email) about how we can help facilitate your learning experience.

As a participant in course discussions, you should also strive to honour the diversity of your classmates. You can do this by: using preferred pronouns and names; being respectful of others opinions and actively making sure all voices are being heard; and refraining from the use of derogatory or demeaning speech or actions.

All members of the class are expected to adhere to the NTU anti-harassment policy. if you witness something that goes against this or have any other concerns, please