Course Requisites (if applicable)

Pre-requisites	For graduate students: No pre-requisites For undergraduates: PH2102 Electromagnetism, PH2103 Thermal Physics
Co-requisites	
Pre-requisite to	
Mutually exclusive to	
Replacement course to	
Remarks (if any)	

Course Aims

This course is an introduction to plasma physics applied to magnetic fusion energy. It will present key nuclear reactions, and the advantages/drawbacks of fusion energy. The course will explain why confining a hot plasma is the best way to produce fusion energy, and how this can be done with intense magnetic fields. In addition, it will introduce the main instabilities that may plague a plasma. Instabilities appear as a potential threat that requires appropriate means of control. Small-scale instabilities lead to a turbulent state that may degrade the confinement properties of a fusion device if not taken care of. Finally, the course will present ways to heat a plasma to reach the conditions needed to start fusion reactions. The course is open to any graduate or under-graduate student with some background in statistical mechanics and electromagnetism. It will also establish connections with other topics such as plasma propulsion, plasma processing, astrophysics and wave propagation in complex media.

Course's Intended Learning Outcomes (ILOs)

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

ILO 1	Compute the fusion power produced by a plasma
ILO 2	Design a magnetic configuration
ILO 3	Compute particle trajectories in a magnetic configuration
ILO 4	Characterise the stability of a magnetised plasma
ILO 5	Estimate a diffusion coefficient due to collisions between charged particles
ILO 6	Estimate a diffusion coefficient due to turbulent processes
ILO 7	Design a radio-frequency heating system
ILO 8	Design a neutral-beam injection heating system
ILO 9	Optimise plasma-wall interactions
ILO 10	Make use of radiative losses to decrease heat load on wall
ILO 11	Design a fusion reactor

Course Content

Thermonuclear Fusion & Magnetic Configuration Thermonuclear fusion Motion of a charged particle in an electromagnetic field Magnetic configuration Equilibrium and MHD Stability Tokamaks Plasma equilibrium Controlling a plasma with external magnetic coils Plasma stability Confinement and Transport Collisional transport Turbulent transport Plasma Heating Ohmic heating Neutral Beam Injection Wave propagation and radio-frequency heating Plasma-wall interaction Open field lines and boundary layer A simplified model of the edge boundary layer Operational regimes Impurities and radiative losses Designing a fusion reactor

Reading and References (if applicable)

J. P. Freidberg, “Plasma Physics and Fusion Energy”, (Cambridge University Press, 2007) R. J. Goldston, P. H. Rutherford, “Introduction to plasma physics and controlled fusion” (Taylor & Francis, Inc. 1995) J. D. Jackson, “Classical Electrodynamics”, 3rd edition, (Wiley, New York, 1998) J. Wesson, Tokamaks, 2nd edition, (Clarendon Press, Oxford, 1997) R.D. Hazeltine and J.D. Meiss, “Plasma Confinement" (Dover, 1992) P. H. Diamond and S-I. Itoh and K. Itoh, “Modern Plasma Physics, vol. 1, Physical Kinetics of Turbulent Plasmas" (Cambridge University Press, 2010) T.H. Stix, “Waves in plasmas”, Springer (1962) P. Stangeby "The plasma boundary of magnetic fusion devices", IOP Editors (2000)

Planned Schedule

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
1	Thermonuclear fusion	1		In-person	
2	Charged particle motion in electromagnetic fields. Magnetic configurations.	2,3			Read lecture notes Prepare exercises Further reading (optional): Freidberg, Goldston
3	Tokamaks, plasma equilibrium, plasma control with external magnetic coils	4		In-person	Read lecture notes Prepare exercises Further reading (optional): Jackson, Wesson
4	MHD stability	4		In-person	Read lecture notes Prepare exercises Further reading (optional): Freidberg, Goldston, Wesson
5	Collisional transport	5		In-person	Read lecture notes Prepare exercises Further reading (optional): Goldston, Hazeltine & Meiss

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
6	Turbulent transport, basics	6		In-person	Read lecture notes Prepare exercises Further reading (optional): Diamond, Itoh & Itoh
7	Turbulent transport, control	6		In-person	Read lecture notes Prepare exercises Further reading (optional): Diamond, Itoh & Itoh
8	Ohmic heating, Neutral Beam Injection	7		In-person	Read lecture notes Prepare exercises Further reading (optional): Wesson
9	Wave propagation and radio-frequency heating	8		In-person	Read lecture notes Prepare exercises Further reading (optional): Wesson, Stix
10	Open field lines and boundary layer	9			Read lecture notes Prepare exercises Further reading (optional): Stangeby

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
11	A simplified model of the edge boundary layer, operational regimes	9		In-person	Read lecture notes Prepare exercises Further reading (optional): Stangeby
12	Impurities and radiative losses	10		In-person	Read lecture notes Prepare exercises Further reading (optional): Stangeby
13	Conclusion and recap: designing a fusion reactor	11		In-person	Read lecture notes Further reading (optional): Wesson, Freidberg

Learning and Teaching Approach

Approach	How does this approach support you in achieving the learning outcomes?
Lectures	Previous lecture will be reviewed first, with answers provided to questions from students. Lectures will alternate presentations of general concepts with treatments of specific problems. Material presentations are based on slides, animations and whiteboard. Comprehensive lecture notes will be provided.
Tutorials	Students will make individual presentations to solve assigned exercises, with detailed explanations. The instructor will comment, clarify technical points, and open perspectives.
Homework	Homework problems will be assigned after each lecture and corrected during tutorials. Discussions with group members are allowed if difficulties are met, but solution will be devised on an individual basis. Each student in turn will present the solution he found and get a mark. This process will allow in depth understanding and improvement of calculation skills.
Technology enhanced Learning (TEL)	PowerPoint slides with animations embedded will be used during the lectures.

Assessment Structure

Assessment Components (includes both continuous and summative assessment)

No.	Component	ILO	Related PLO or Accreditation	Weightage	Team/Individual	Rubrics	Level of Understanding
1	Summative Assessment (EXAM): Others([final examination])	All		60	Individual	Analytic	Not Applicable
2	Continuous Assessment (CA): Others([assignments (e.g. term paper, essay)] CA - Homework)	All		20	Individual	Analytic	Not Applicable
3	Continuous Assessment (CA): Others([quiz/test])	1, 2, 3, 4, 5, 6		20	Individual	Analytic	Not Applicable

Description of Assessment Components (if applicable)

Formative Feedback

Questions are expected from students during tutorials - verbal formative feedback will be given. Instructor will ask quick questions, to check key concepts are captured.

Homework will be corrected, and feedback given in weekly tutorials, with emphasis on key concepts, and use of alternative methods to solve exercises.

Formative feedback will be given after the midterm exam to identify common mistakes and check on learned topics.

Discussions in person will be encouraged after lectures/tutorials.

NTU Graduate Attributes/Competency Mapping

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

Attributes/Competency	Level
Creative Thinking	Intermediate
Curiosity	Intermediate
Learning Agility	Advanced
Problem Solving	Intermediate
Critical Thinking	Intermediate

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)

Policy (Absenteeism)

If you are sick and unable to attend your class / Mid-term quizzes, you have to:

Send an email to the instructor regarding the absence and request for a replacement class and make-up mid-term quizzes.

Submit the original Medical Certificate* or official letter of excuse to administrator.

Attend the assigned replacement class (subject to availability) and make-up mid-term quizzes.

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

Policy (Others, if applicable)

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