Academic Year	2023/24	**Semester**	1
School/Programme	SPMS		
Course Coordinator	Prof Xavier GARBET		
Course Code	PH7027		
Course Title	Plasma Physics and Fusion Energy		
Pre-requisites	For graduate students: No pre-requisites For undergraduates: PH2102 Electromagnetism, PH3201 Statistical Mechanics		
No of AUs	4		
Contact Hours	52 contact hours		
Proposal Date **i.e. date proposal was drafted**	November 2022		
Expected Implementation date of new/revised course	August 2023		
Suggested Class Size	30		
Any cross-listing? **Is course opened to all Postgraduate students (including IGP) or specific program (please indicate)?**	Yes, SPMS Master by Research		

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.

Intended Learning Outcomes (ILO)

By the end of this course, you should be able to:

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

Course Content

1. Thermonuclear Fusion & Magnetic Configuration
   - 1.1 Thermonuclear fusion
   - 1.2 Motion of a charged particle in an electromagnetic field
   - 1.3 Magnetic configuration
2. Equilibrium and MHD Stability
   - 2.1 Tokamaks
   - 2.2 Plasma equilibrium
   - 2.3 Controlling a plasma with external magnetic coils
   - 2.4 Plasma stability
3. Confinement and Transport
   - 3.1 Collisional transport
   - 3.2 Turbulent transport
4. Plasma Heating
   - 4.1 Ohmic heating
   - 4.2 Neutral Beam Injection
   - 4.3 Wave propagation and radio-frequency heating
5. Plasma-wall interaction
   - 5.1 Open field lines and boundary layer
   - 5.2 A simplified model of the edge boundary layer
   - 5.3 Operational regimes
   - 5.4 Impurities and radiative losses
6. Designing a fusion reactor

Assessment (includes both continuous and summative assessment)

Note: It is advised that Group component and class participation should not be more than 40% and 20% respectively, unless with good justification.

Component	ILO Tested	Weighting	Team/Individual	Assessment Rubrics
1. Final Examination	All	60%	Individual	Point-based marking (not rubric based)
2. CA1: Homework	All	20%	Individual	Point-based marking (not rubric based)
3. CA2: Mid-term examination	1-6	20%	Individual	Point-based marking (not rubric based)
Total		100%		

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.

Learning and Teaching Approach

Note: Please include and indicate TEL component.

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 PowerPoint 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.

Reading and References

- 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)

Course Policies and Student Responsibilities

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

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

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

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
Xavier GARBET	PAP-05-01	65138095	xavier.garbet@ntu.edu.sg

Industry Participation

Company Name	Description of involvement (e.g., co-curation of course, speaker or instructor), include no. of course hours if known.	Contact Person	Email
A*STAR	Guest speaker, 3 hours	Valerian Hall-Chen	Valerian_Hall-Chen@ihpc.a-star.edu.sg

Planned Weekly Schedule

Week	Topic	ILO	Readings/ Activities
Week 1	Thermonuclear fusion	1	
Week 2	Charged particle motion in electromagnetic fields. Magnetic configurations.	2,3	Read lecture notes Prepare exercises Further reading (optional): Freidberg, Goldston
Week 3	Tokamaks, plasma equilibrium, plasma control with external magnetic coils	4	Read lecture notes Prepare exercises Further reading (optional): Jackson, Wesson
Week 4	MHD stability	4	Read lecture notes Prepare exercises Further reading (optional): Freidberg, Goldston, Wesson
Week 5	Collisional transport,	5	Read lecture notes Prepare exercises Further reading (optional): Goldston, Hazeltine & Meiss
Week 6	Turbulent transport, basics	6	Read lecture notes Prepare exercises Further reading (optional): Diamond, Itoh & Itoh
Week 7	Turbulent transport, control	6	Read lecture notes Prepare exercises Further reading (optional): Diamond, Itoh & Itoh
Week 8	Ohmic heating, Neutral Beam Injection	7	Read lecture notes Prepare exercises Further reading (optional): Wesson
Week 9	Wave propagation and radio-frequency heating	8	Read lecture notes Prepare exercises Further reading (optional): Wesson, Stix
Week 10	Open field lines and boundary layer	9	Read lecture notes Prepare exercises Further reading (optional): Stangeby
Week 11	A simplified model of the edge boundary layer, operational regimes	9	Read lecture notes Prepare exercises Further reading (optional): Stangeby

Week 12	Impurities and radiative losses	10	Read lecture notes Prepare exercises Further reading (optional): Stangeby
Week 13	Conclusion and recap: designing a fusion reactor	11	Read lecture notes Further reading (optional): Wesson, Freidberg

Other information(s)

Nil.