Nanyang Technological University
Division of Physics and Applied Physics

Academic Year	AY23/24	**Semester**	2
Course Coordinator	Asst Prof. Zhisong Qu		
Course Code	PH3407		
Course Title	Introduction to Plasma Physics		
Pre-requisites	PH2102 Electromagnetism and PH2103 Thermal Physics		
Mutually Exclusive	Nil		
No of AUs	3 AU		
Contact Hours	Lectures: 26 hours (2 hr per week); Tutorial: 13 hours (1 hr per week)		
Proposal Date	10 Jul 2023		

Course Aims

Plasma, also known as the "fourth state of matter", is common in the universe: more than 90% of the baryonic matter in the universe is believed to be in the plasma state. This course introduces the basic plasma physics: the concept of plasmas, the theories describing it, and some of its unique phenomena. We also aim to facilitate the students with some common problem-solving skills, both analytically and numerically. Finally, we will cover their applications in solar physics, astrophysics, nuclear fusion reactors, industry, and daily life.

Intended Learning Outcomes (ILO)

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

1. Define a plasma, identify their appearance in various environments, and calculate their relevant parameters.
2. Construct the fluid equations for plasmas and discuss the suitability of various assumptions.
3. Derive and solve the wave dispersion relationships of homogenous plasmas, estimate the wave frequencies, identify their relevancy and applications.
4. Illustrate how plasmas form equilibrium states, compute their profiles.
5. Discuss the concept of stability, determine if a plasma is stable or not, classify various types of instabilities, and compute their growth rate.
6. Explain the kinetic description of plasmas and the Vlasov equation, and construct the fluid equations from taking the moments. Explain and derive Landau damping.
7. Describe charge particle motions in electromagnetic field, identify the invariants of motion, and compute the particle orbits.
8. Explain drift ordering in a strong magnetic field.
9. Identify and distinguish the characteristics of Coulomb collisions and neutral collisions. Compute the plasma collision rate and the resistivity. Estimate the plasma diffusion rate and differentiate the transport regimes. Construct the plasma profile.
10. Illustrate the application of plasmas. Discuss the applicability of theories covered in the course.

Course Content

1. What is a plasma?
   - Plasma frequency, Debye length, and quasi-neutrality
   - Natural plasmas, laboratory plasmas, and their parameters
2. Fluid description of plasmas
   - Derivation of the fluid equations
   - Magnetohydrodynamics (MHD)
3. Plasma waves in homogenous media

- Linearisation of the fluid equations
- Waves in unmagnetized plasmas
- Waves in magnetized plasmas
- Alfvén waves

4. Plasma equilibrium
   - MHD equilibrium
   - Equilibrium in simple geometries, astrophysics objects, and fusion devices
5. Stability
   - Rayleigh-Taylor instabilities
   - Tearing instabilities, magnetic reconnections, solar flare
   - Other important instabilities in natural and lab plasmas
6. Kinetic theory
   - Plasma as a distribution function
   - The Vlasov equation, fluid equation derivation revisit
   - Landau damping
7. Plasmas in a strong magnetic field
   - Guiding centre drift in uniform E and B fields
   - Guiding centre drift in non-uniform and time-varying fields
   - Adiabatic invariants
   - Drift ordering
8. Collisions and transport
   - Coulomb collisions, neutral collisions
   - Plasma resistivity
   - Diffusion and transport
9. Applications
   - Solar and astrophysical plasmas, nuclear fusion reactor, industrial plasmas, etc

Assessment (includes both continuous and summative assessment)

Component	Course LO Tested	Related PLO or Accreditation	Weightage	Team /Individual	Rubrics
1. Mid-term test	1-5	Curiosity (A) Learning Agility (I) Problem Solving (I) Sense Making (I)	20	Individual	Point-based marking (not rubric based)
2. Assignments	All	Care for Environment (B) Curiosity (A) Learning Agility (I) Problem Solving (I) Sense Making (I)	20	Individual	Point-based marking (not rubric based)

3. Final examination	All	Curiosity (A) Learning Agility (I) Problem Solving (I) Sense Making (I)	60	Individual	Point-based marking (not rubric based)
			100%		

Formative feedback

Formative feedback is given through discussion within tutorials. We will hold TA meetings regularly to discuss the progress and difficulty level of the course.

Feedback will be given after assignments and mid-term test to highlight the common mistakes and misunderstandings.

Past exam questions will be made available starting from the second offering.

The student can contact the lecturer after class or via email for individual questions and feedbacks.

Learning and Teaching approach

Approach	How does this approach support you in achieving the learning outcomes?
Lectures	Applications will be introduced first to motivate the topic. The fundamental concepts and the theory will then be introduced and discussed. Finally, the concepts are utilized to further explain the application.
Tutorial	Review and discussion of key concepts from lectures with TAs, by working through problems. The TAs will monitor and provide timely feedback.
Assignments	There will be 6 take-home written assignments mostly consisting of short answer questions. The assignments will consolidate the learning outcomes by providing students with a chance to practice their knowledge.
Mid-term test	Mid-term test is used to motivate and assess your understandings after the recess week.

Reading and References

1. Chen, F. F. (2015). *Introduction to Plasma Physics and Controlled Fusion.* Springer International Publishing AG. ISBN: 9783319223087 (Full text available online in NTU library)

2. Choudhuri, A. R. (1998). *The physics of fluids and plasmas: an introduction for astrophysicists*. Cambridge University Press. ISBN: 9780521554879

3. Goldston, R. J. and Rutherford, P. H. (1995). *Introduction to plasma physics.* CRC Press. ISBN : 9781439822074 (Full text available online in NTU library)

NOTE: Reading list will be updated as and when necessary to be up-to-date.

Course Policies and Student Responsibilities

(1) General

You are expected to complete all assigned pre-class readings and activities, attend all tutorial classes punctually and take all scheduled assignments and tests by due dates. You are expected to participate in all tutorial discussions and activities.

(2) Absenteeism

Absence from the mid-term 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.

If you are sick and unable to attend your class (particularly the mid-terms), you must:

1. Contact the lecturer to schedule an oral make-up exam within two weeks.
2. Submit the Medical Certificate* to administrator.

* 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.

Use of Generative Artificial Intelligence (GAI) such as ChatGPT is allowed in the course but students need to adhere to NTU's prevailing guideline. i.e. **Give proper citations if you use any AI tool**. Extending the practice of correctly citing references in your work under NTU's policies on citation and plagiarism, the University requires students to **(i) identify any generative AI tools used** and **(ii) declare how the tools are used in submitted work**. Please note that even with acknowledgement, copying of output generated by AI tools (in part or whole) may still be regarded as plagiarism.

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
Asst Prof. Zhisong Qu	SPMS-PAP-03-12	63167899	zhisong.qu@ntu.edu.sg

Planned Weekly Schedule

Week	Topic	Course LO	Readings/ Activities
1	What is a plasma?	**1**	Book 1, Chapter 1 Tutorial
2	Plasma as fluids, magnetohydrodynamics	**2**	Book 1, Chapter 3 Tutorial Assignment 1
3	Waves in homogenous unmagnetized plasmas	**3**	Book 1, Chapter 4 Tutorial
4	Waves in homogenous magnetized plasmas	**3**	Book 1, Chapter 4 Tutorial Assignment 2
5	Equilibrium	**4**	Book 1, Chapter 6 Tutorial
6	Instabilities	**5**	Book 1, Chapter 6 Tutorial Assignment 3
7	Kinetic description of plasmas	**6**	Book 1, Chapter 7 Tutorial
8	Landau damping	**6**	Book 1, Chapter 7 Mid-term test Tutorial Assignment 4
9	Single particle motions, adiabatic invariant	**7**	Book 1, Chapter 2 Tutorial
10	Strong magnetic field	**8**	Book 3, Chapter 21 Tutorial Assignment 5
11	Collisions, resistivity	**9**	Book 1, Chapter 5 Tutorial
12	Diffusion and transport	**9**	Book 1, Chapter 5 Tutorial/ Assignment 6
13	Applications	**10**	Book 1, Chapter 10 Tutorial