

NPRE 421: Plasma and Fusion Science

Course Syllabus

Spring 2024

Department of Nuclear, Plasma, and Radiological Engineering, University of Illinois at Urbana-Champaign

Course description:

Physics of plasmas, including particle and fluid descriptions, waves, collisions, stability, and confinement, with applications to controlled thermonuclear fusion reactors, problems in fusion engineering, and astrophysics.

Course credit: 3 undergraduate hours, 3 graduate hours

Course prerequisites: NPRE 321.

Staff:

Instructor: Prof. Mohan Sankaran, 111H Talbot Lab, rmohan@illinois.edu

TA: Md Fazlul “Huq” Huq, 225A Talbot Lab, mfhug2@illinois.edu

Lectures: TTh 9:30-10:50 am, 1035 CIF

Office hours: TTh 11-12 pm, 111H Talbot Lab (Sankaran)
F 3:30-5:30 pm, 225A Talbot Lab (Huq)

Course materials:

- Lecture notes
- Strongly recommended textbooks:
 - *Plasma Physics and Fusion Energy*, Jeffrey P. Freidberg
 - *Introduction to Plasma Physics and Controlled Fusion*, Francis F. Chen, Springer, NY.
- Suggested supplementary textbooks:
 - *Fundamentals of Plasma Physics*, Paul M. Bellan, Cambridge University Press.
- Learning management software: Canvas.
 - <https://canvas.illinois.edu/>
 - All lectures will be available for remote connection and will be recorded to the Cloud via Zoom (link on Canvas).
 - Course material will be made available through Canvas. Students are required to access materials added by the instructor for each class: lecture notes, video recordings, assigned readings, homework assignments, etc.

Course objectives:

This course will give you a fundamental and quantitative understanding of plasmas. Specifically, the course is structured into three parts: 1) single particle motion, 2) fluid equations, and 3) fusion energy.

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

- Understand what is a plasma and determine the appropriate criteria and properties including Debye shielding
- Explicitly describe single particle motion in various fields, including uniform, non-uniform, and time-dependent
- Understand Coulomb collisions for two-body and between single particle and background particles
- Understand Boltzmann kinetic equation
- Understand and be able to take moments of equations
- Recognize Vlasov, two-fluid, MHD, and Braginskii equations
- Understand different types of fusion reactors
- Write out basic fusion reactions and relate power generation and power balance

Course grading:

25%	Homework
30%	Midterm exam
40%	Final exam
5%	Class attendance and participation

Grading policy:

Homeworks will be assigned approximately every 1-2 weeks, usually posted online on Tuesdays and due the following Tuesday before class. The specific due dates will be given with the assignment. Assignments should be submitted electronically on Canvas. If you are preparing assignments by hand, you must scan or take a photo of them and ensure the submitted version is clear to help us with grading. There will be a late penalty of 10% per day for late submissions, up to a maximum of 5 days (which would be a total of 50% penalty), and assignments that are not legible will not be accepted (0%). After 5 days, the assignment will receive a 0% unless the instructor is contacted before the due date and gives a special extension.

On homework assignments, you are welcome to and in fact, encouraged to work together. Working together means setting up problems together, checking final solutions, helping each other get started or when someone is stuck, reviewing each other's work, etc. However, each student is expected to turn in their own work – the details of the derivation must be unique and not a direct copy of another person's work. Also, homework is the best process to learn the course material. I

suggest that you try to set up the problems and attempt to do it on your own before working with others. Getting stuck is really an important part of the learning process!

The midterm exam will take place on **Thursday March 7th** during class time and in the regular classroom. The exam will be open book and open notes. If for some reason you are unable to take the exam on this date, you must contact the instructor before the exam. There will be no make-up exam except in extreme circumstances (e.g., death of an immediate family member, sickness, etc.). You may be asked to provide proper documentation.

The final exam will take place at the day/time assigned by the registrar, **Tuesday May 7th 7-10 pm**, in the regular classroom. The exam will be open book and open notes. If for some reason you are unable to take the exam on this date, you must contact the registrar.

In addition to homework and exams, a part of your grade will be based on attendance and in-class participation. We have a small class and there will be ample opportunity to participate. You can ask questions, answer questions I pose, or add comments as part of our discussions in class. To help me assess your participation, I will ask each of you to keep track of what you asked, answered, or discussed, and submit a brief note about your participation by Canvas at the end of each week.

Academic integrity:

The University of Illinois at Urbana-Champaign Student Code should be considered as a part of this syllabus. Students should pay particular attention to Article 1, Part 4: Academic Integrity. Read the Code at the following URL: <http://studentcode.illinois.edu/>.

Academic dishonesty may result in a failing grade. Every student is expected to review and abide by the Academic Integrity Policy: <https://studentcode.illinois.edu/article1/part4/1-401/>. Ignorance is not an excuse for any academic dishonesty. It is your responsibility to read this policy to avoid any misunderstanding. Do not hesitate to ask the instructor(s) if you are ever in doubt about what constitutes plagiarism, cheating, or any other breach of academic integrity.

In-person attendance/COVID-19 policy:

Following University policy, all students are required to engage in appropriate behavior to protect the health and safety of the community. Students are required to follow the campus COVID-19 protocols. Students who test positive for COVID-19 or have had an exposure that requires testing and/or quarantine must follow current recommendations about in-person attendance. The University will provide information to the instructor, in a manner that complies with privacy laws, about students in these latter categories. These students are judged to have excused absences for the class period and should contact the instructor via email about making up the work.

Students need to take responsibility for checking their symptoms every day. Students who feel ill must not come to class and need to email the instructor. These students will have an excused absence as long as the instructor is emailed as soon as possible, preferably ahead of time.

Course calendar:

Dates	Content	Reading
1/16, 1/18	Gas equation of state and kinetic theory	Chen 1.1-1.3
1/18, 1/25 (1/23*)	Intro to plasmas and basic plasma parameters	Chen 1.4-1.6
1/30, 2/1	Single particle motion in uniform fields	Chen 2.1, 2.2
2/6, 2/8	Single particle motion in non-uniform fields	Chen 2.3, 2.4
2/13, 2/15	Motion in time-dependent fields	Chen 2.5-2.8
2/20, 2/22	Coulomb collisions	Friedberg 9.2, 9.3
2/27, 2/29	Momentum and energy exchange	Friedberg 9.7
3/5	Midterm exam review	
3/7	Midterm exam	
3/12, 3/14	Spring break	
3/19, 3/21	Introduction to $f(v)$, moments of $f(v)$	Chen 7.1, 7.2
3/26, 3/28	Boltzmann, two-fluid, Vlasov, and Braginskii equations	Chen 7.3
4/2, 4/4	Diffusion and mobility, ambipolar diffusion	Chen 5.1, 5.2
4/11, 4/16 (4/9*)	Intro to fusion energy and reactions	Friedberg 1, 2
4/16, 4/18	Fusion power generation and power balance	Friedberg 3, 4
4/23, 4/25	Magnetic fusion concepts	Friedberg 13
4/30	Final exam review	
5/7	Final exam 7-10 pm	

*I will be traveling and lecture will either be replaced by problem solving session run by TA, or cancelled.