Syllabus – PHYS 626 – Fall 2023

Course Information:

PHYS 626:	Fundamentals of Plasma Physics, 3 credits, Fall 2023
Meeting Times:	MWF 11:45-12:45
Meeting Location:	Reichardt 207

Instructor Information:

Instructor:	Peter Delamere, Professor of Space Physics
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Office Hours:	by appointment

Prerequisites: Undergraduate E&M, undergraduate differential and partial differential equations, experience in programming, or permission of the instructor.

Course Description: Plasma physics is the study of ionized and partially ionized gases and their collective interaction with electromagnetic fields. The dynamics of a plasma requires a self-consistent solution of the particle dynamics and the electromagnetic field equations. The objective of this course is to systematically develop analytical tools for understanding plasma physics. Specifically, we will start with single particle motion in prescribed electric and magnetic fields to understand the kinetic underpinnings of plasmas. Utilizing the tools of statistical mechanics, we will develop a kinetic theory for studying the self-consistent interaction between a collection of particles and the electromagnetic fields. Eventually, a kinetic approach can be "simplified" to a set of fluid equations – or magnetohydrodynamic equations– that serve as a convenient framework for understanding macroscopic plasma dynamics and equilibria. While certain phenomena (e.g., waves) can be understood with linear theory, plasmas are intrinsically nonlinear, exhibiting nonlinear plasma waves and instabilities. The specific topics that will be covered (not necessarily in order) are:

- Single charge particle motion in the electromagnetic fields
- Plasma kinetic theory
- Vlasov equations for collisionless plasmas
- Magnetohydrodynamic equations
- MHD Shocks and Discontinuity
- Linear plasma waves and instabilities
- Nonlinear plasma waves and instabilities

Approach: The course is intended to provide a basic understanding of plasma physics and its application to space physics. While detailed application of the mathematical tools developed in this course are generally reserved for other elective courses (e.g., Space Physics, Magnetospheric Physics, Aeronomy and Auroral Physics), several space physics applications will be highlighted to promote physical insights and intuition whenever possible. Due to convenience of the fluid (magnetohydrodynamic) equations for developing macro-scale intuition, we will initially streamline the coverage of kinetic theory to access the fluid equations, and then revisit kinetic theory in greater depth later in the semester.

Student learning outcomes Upon completion of this course, students should be able to:

- Qualitatively and quantitatively describe the motion of charged particles in a dipole magnetic field.
- Derive the fluid equations
- Analyze the conditions for MHD equilibria
- Describe MHD wave propagation in a magnetized plasma with particular emphasis given to momentum and energy transport by Alfvén waves.
- Analyze the jump conditions at MHD shocks and discontinuities.
- Understand the origin of plasma waves from two fluid equations and the Vlasov equation.
- Understand the origin of plasma instabilities.

Textbook: There is no textbook requirement for this course. But the following textbooks are highly recommended:

D. R. Nicholson, *Introduction to Plasma Theory*, John Wiley & Sons Inc (June 1, 1983), ISBN-10: 047109045X, ISBN-13: 978-0471090458 (Unfortunately this book is out of print but it is available in the GI-IARC Library).

George Parks, *Physics of Space Plasmas: An Introduction, Second Edition*, Westview Press (2003), ISBN-10: 0813341302.

D. A. Gurnett and A. Bhattacharjee, *Introduction to Plasma Physics*, Cambridge, 2005 (ISBN 0 521 36730 1 paperback).

Francis F Chen, *Introduction to Plasma Physics and Controlled Fusion, Volume 1: Plasma Physics*, Plenum Press, 2nd Edition, 1984.

Tom Cravens, *Physics of Solar System Plasmas*, Cambridge University Press, 1997.

Krall and Trivelpiece, *Principles of Plasma Physics*, San Francisco Press (1986).

Baumjohann and Treumann, *Basic Space Plasma Physics*, Imperial College Press (1997).

Fletcher, *Computational Techniques for Fluid Dynamics, I and II*, Springer (1988):

Potter, *Computational Physics*, John Wiley (1973)

Birdsall and Langdon, *Plasma Physics via Computer Simulation*, IOP (1995, based on 1985 original)

Stephan Jardin, *Computational Methods in Plasma Physics*, Chapman & Hall/CRC Computational Science Series:

Programming languages: Students are welcome to submit programming solutions in the language of their choice. Recommended languages for this course are Matlab, IDL, and Python.

Grading:

Homework	50%
Midterm Exam	20%
Final Exam	30%

Course Policies:

(a) Attendance and participation in class is expected of all students.

(b) Assignments are due at the beginning of class on the due date.

(c) Students are encouraged to work together on homework problems, but the final written solutions must be individual work.

(d) Students must acknowledge all sources of information – included fellow students – used in homework solutions and final projects. The UAF catalog states: "The university may initiate disciplinary action and impose disciplinary sanctions against any student or student organization found responsible for committing, attempting to commit or intentionally assisting in the commission of . . . cheating, plagiarism, or other forms of academic dishonesty. . . "

(e) All UA student academics and regulations are adhered to in this course. You may find these in the UAF catalog (section "Academics and Regulations").

COVID-19 statement: Students should keep up-to-date on the university's policies, practices, and mandates related to COVID-19 by regularly checking this website: https://sites.google.com/alaska.edu/coronavirus/uaf?authuser=0 Further, students are expected to adhere to the university's policies, practices, and mandates and are subject to disciplinary actions if they do not comply.

Student protections statement: UAF embraces and grows a culture of respect, diversity, inclusion, and caring. Students at this university are protected against sexual harassment and discrimination (Title IX). Faculty members are designated as responsible employees which means they are required to report sexual misconduct. Graduate teaching assistants do not share the same reporting obligations. For more information on your rights as a student and the resources available to you to resolve problems, please go to the following site: https://catalog.uaf.edu/academics-regulations/students-rights-responsibilities/.

Disability services statement: I will work with the Office of Disability Services to provide reasonable accommodation to students with disabilities.

ASUAF advocacy statement: The Associated Students of the University of Alaska Fairbanks, the student government of UAF, offers advocacy services to students who feel they are facing issues with staff, faculty, and/or other students specifically if these issues are hindering the ability of the student to succeed in their academics or go about their lives at the university. Students who wish to utilize these services can contact the Student Advocacy Director by visiting the ASUAF office or emailing asuaf.office@alaska.edu.

Student Academic Support:

- Speaking Center (907-474-5470, uaf-speakingcenter@alaska.edu, Gruening 507)
- Writing Center (907-474-5314, uaf-writing-center@alaska.edu, Gruening 8th floor)
- UAF Math Services, uaf-traccloud@alaska.edu, Chapman Building (for math fee paying students only)
- Developmental Math Lab, Gruening 406
- The Debbie Moses Learning Center at CTC (907-455-2860, 604 Barnette St, Room 120, https://www.ctc.uaf.edu/student-services/student-success-center/)
- For more information and resources, please see the Academic Advising Resource List (https://www.uaf.edu/advising/lr/SKM_364e19011717281.pdf)

Student Resources:

- Disability Services (907-474-5655, uaf-disability-services@alaska.edu, Whitaker 208)
- Student Health & Counseling [6 free counseling sessions] (907-474-7043, https://www.uaf.edu/chc/appointments.php, Gruening 215)
- Center for Student Rights and Responsibilities (907-474-7317, uaf-studentrights@alaska.edu, Eielson 110)
- Associated Students of the University of Alaska Fairbanks (ASUAF) or ASUAF Student Government (907-474-7355, asuaf.office@alaska.edu, Wood Center 119)

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UAF Department of Equity and Compliance
1692 Tok Lane, 3rd floor, Constitution Hall, Fairbanks, AK 99775
907-474-7300
uaf-deo@alaska.edu

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- There are supportive measures available to individuals that may have experienced discrimination.
- University of Alaska's Board of Regents' Policy & University Regulations (UA BoR P&R) 01.02.020 Nondiscrimination and 01.04 Sex and Gender-Based Discrimination Under Title IX, go to: http://alaska.edu/bor/policy-regulations/.
- UA BoR P&R apply at all university owned or operated sites, university sanctioned events, clinical sites and during all academic or research related travel that are university sponsored.

For further information on your rights and resources go to https://www.alaska.edu/equity/title-ix/student-placement-guidelines/.

Schedule:

Topic	Week	Dates
Plasma Basics	1	Aug 28
Single Particle Motion	1	Aug 30 - Sept 1
Labor Day–no class	2	Sept 4
Kinetic Theory I: phase space and distribution functions	2	Sept 6-8
Derivation of the fluid equations	3	Sept 11-15
Magnetohydrodynamic (MHD) equations	4	Sept 18-22
Properties of MHD (Frozen in condition, entropy)	5	Sept 25-29
MHD equilibria	6	Oct 2 - 6
MHD stability and waves	7	Oct 9 - 13
Midterm Exam	8	Oct 16
MHD shocks and discontinuities	8	Oct 18 - 20
Magnetic reconnection	9	Oct 23 - 27
Fluid instabilities	10	Oct 30 - Nov 3
Two-fluid equation and waves	11	Nov 6 - 10
Kinetic theory II: Klimontovich Equation	12	Nov 13 - 17
Kinetic theory II: Liouville & Lenard-Balescu equations	13	Nov 20
Thanksgiving break–no class	13	Nov 22-24
Vlasov Equation and waves	14-15	Nov 27 - Dec 6
Review	15	Dec 8
Final exam	16	10:15– 12:15, Friday, Dec 15