Syllabus – PHYS 626 – Fall 2015

Course Information:

PHYS 626:	Fundamentals of Plasma Physics, 3 credits, Fall 2015
Meeting Times:	MWF 11:45-12:45
Meeting Location:	Reichardt 207

Instructor Information:

Instructor:	Peter Delamere, Associate 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	60%
Midterm Exam	15%
Final Exam	25%

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").

Students with Disabilities Notice: The University of Alaska Fairbanks is committed to equal opportunity for students with disabilities. Students with disabilities are encouraged to contact the coordinator of Disability Services (Mary Matthews) at the Center for health & Counseling (x7043). See section on Disability Services of the UAF Class Schedule (http://www.uaf.edu/schedule/).

Schedule:

Topic	Week	Dates
Plasma Basics	1	Sept 4
Labor Day–no class	2	Sept 7
Single Particle Motion	2	Sept 9 - 11
Kinetic Theory I: phase space and distribution functions	3	Sept 14-18
Derivation of the fluid equations	4	Sept 21-25
Magnetohydrodynamic (MHD) equations	5	Sept 28 - Oct 2
Properties of MHD (Frozen in condition, entropy)	6	Oct 5-9
MHD equilibria	7	Oct 12 - 16
MHD stability and waves	8	Oct 19 - 21
Midterm Exam	8	Oct 23
MHD shocks and discontinuities	9	Oct 26 - 30
Magnetic reconnection	10	Nov 2 - 6
Fluid instabilities	11	Nov 9 - 13
Two-fluid equation and waves	12	Nov 16 - 20
Kinetic theory II: Klimontovich Equation	13	Nov 23 - 25
Thanksgiving break–no class	13	Nov 27
Kinetic theory II: Liouville & Lenard-Balescu equations	14	Nov 30 - Dec 4
Vlasov Equation and waves	15	Dec 7 -11
Review	16	Dec 14
Final exam	17	Dec 18, 10:15 -12:15